- Failed fuel assemblies
- Operator error followed by corrective action
- Any seismic event

Waste handling and confinement systems will be equipped with instrumentation to continuously monitor the condition and performance of the equipment. Improper operation, which includes exceeding component, process, electrical power, load, environment, and interface limits, will trigger an alarm that is displayed at the operator and supervisory stations.

The primary components for equipment that is "important to radiological safety" will be redundant and fail-safe. In addition, this equipment will be furnished with standby power and the independent controls required for recovery operations during a given design basis event. Equipment, instruments, lighting, and controls that are required to support waste package recovery will be provided with uninterruptible power supplies. Any equipment handling loaded casks, canisters, waste packages, or fuel assemblies will automatically stop and hold its load if the power or a critical control component fails. Equipment designs will also consider human factors to minimize the possibility of design basis events being caused by human error. Particular attention will be focused on equipment whose failure could potentially lead to a radiological release.

Ventilation systems for facility areas that may potentially be exposed to radiation will be monitored continuously for any signs of blockage or failure to properly ventilate a confinement area. Process systems, including site-generated radiological waste collection and pool systems, will be monitored for leaks. Waste handling, transport, and emplacement systems will be equipped with avoidance systems, speed controls, and interlocks to minimize the potential for collisions. Equipment will be designed, located, or protected so that the failure of a structure, system, or component will not cause the failure—during a design basis event—of another structure, system, or component that is important to radiological safety and is required to function in during that design basis event.

A waste package remediation system will handle off-normal conditions for loaded waste packages or retrieved waste packages. Either the off-normal condition (e.g., welds that do not meet specification) will be corrected, or the waste package will be opened and the fuel assemblies or canisters removed and loaded into another disposal container. Failed fuel assemblies will be moved to set-aside areas where they will be confined and packaged for later disposal.

Mitigation and cleanup systems, including remotely operated cleanup systems, will be designed to operate during off-normal conditions that result in a radiological release. Operators and maintenance technicians will be certified and periodically retrained to minimize the potential of operator and maintenance errors. Off-normal operating, maintenance, and recovery procedures will be developed and verified. These procedures will be updated periodically, based on operator experience, and reverified.

During the monitor phase, all surface facilities (with the exception of those required to conduct maintenance and respond to emergencies) will be decontaminated, as required, to ensure that residual contamination is removed to within permissible levels for unrestricted use. Decontamination activities include surveying, identifying, and characterizing contaminated areas and facilities. Decontamination work will also include determining the removal methods and degree of treatment needed, as well as packaging, immobilizing, and transporting low-level radioactive waste to either an onsite or offsite disposal or storage location.

During waste handling operations, the potential for radiological contamination exists where unconfined radioactive materials are handled and where contamination is present on incoming casks/canisters within the Waste Handling Building. Other potential sources of contamination within the Waste Treatment Building include transfer cells, decontamination stations, high-efficiency particulate air filters, and heating, ventilation and air conditioning ducts, all of which may require decontamination or packaging for removal.

Permanent closure will include closing the subsurface facilities, decontaminating and decommissioning the surface facilities, restoring the site, and establishing institutional barriers (see Section 4.3).

6.2.2 Subsurface Operations

The following sections describe how waste packages are transported to the subsurface, through the perimeter main drifts, to the emplacement drift. The process and equipment used to unload the waste package and place it in the emplacement drift are also described.

A waste package ready for transport underground will be secured on a reusable rail car that is retracted into the waste package transporter. The transporter is a shielded cask mounted on a rail car. A locomotive will be coupled to each end of the transporter at the Waste Handling Building loading facility. The two locomotives will move the transporter into and down the north ramp and into the east or west drift (see Figure 6-3). At the selected emplacement drift, one locomotive will be uncoupled. The remaining locomotive will back the transporter against the transfer dock at the emplacement drift entrance.

After the waste package transporter is positioned at the transfer dock in front of the emplacement drift isolation door, and the drift isolation door opened, the transporter door will be opened and rail continuity with the emplacement drift track will be established. The transporter is equipped with a self-contained mechanism that will push the reusable rail car through the emplacement drift door and position it for unloading (see Figure 6-4). A self-propelled, remotely operated emplacement gantry, which is stationed in the emplacement drift during active emplacement operations, will move into position over the reusable rail car. The gantry will then engage the waste package and lift it from the rail car by the skirt flanges on either end.

The emplacement gantry will lift the waste package clear of the reusable rail car and shadow shield and carry it though the emplacement drift to its preselected emplacement location. The gantry will then lower the waste package onto the V-shaped steel supports, disengage from the waste package, and return to a position near the emplacement drift door.

After the waste package is removed from the reusable rail car, the waste package transporter will retract the reusable rail car and close its doors. The primary locomotive will pull the transporter away from the transfer dock and be recoupled with the secondary locomotive in the main drift. The locomotives will then return the transporter to the Waste Handling Building at the surface, where it will be loaded again. The emplacement drift doors will be closed after the transporter departs, completing the emplacement cycle.

If a waste package has to be moved during or after emplacement (not including retrieval operations), it will be removed from the emplacement drift by following the emplacement operations in reverse order. The waste package will be placed into the waste package transporter and returned to the surface facilities for examination. Additional steps required to move the waste packages may include cooling the emplacement drift before any equipment enters and using remote inspection methods to determine if there are any obstructions to travel in the emplacement drifts. Emplaced waste packages that obstruct access to the container to be removed will be transferred to and temporarily stored in a vacant drift.

Examples of potential subsurface design basis events include the following:

- Loss of offsite power
- Derailment of transporter
- Fire
- Breach of waste package

The subsurface facility will include a monitoring system that is designed to detect and mitigate a subsurface fire. Detection of an underground fire will prompt the sounding of alarms, notification of subsurface work areas, and implementation of prearranged evacuation plans. All subsurface person-

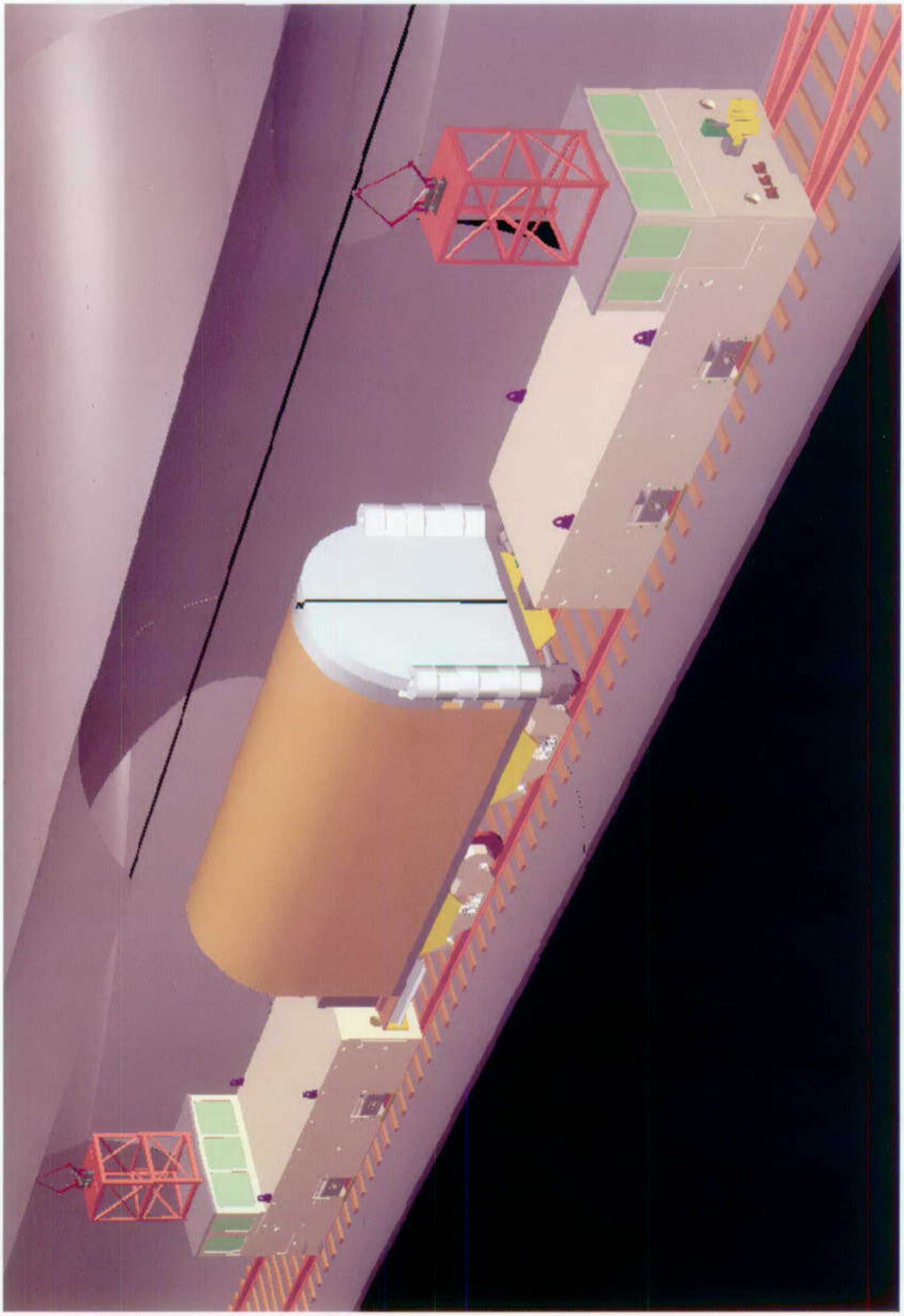

Figure 6-3. Locomotive/Transporter Arrangement

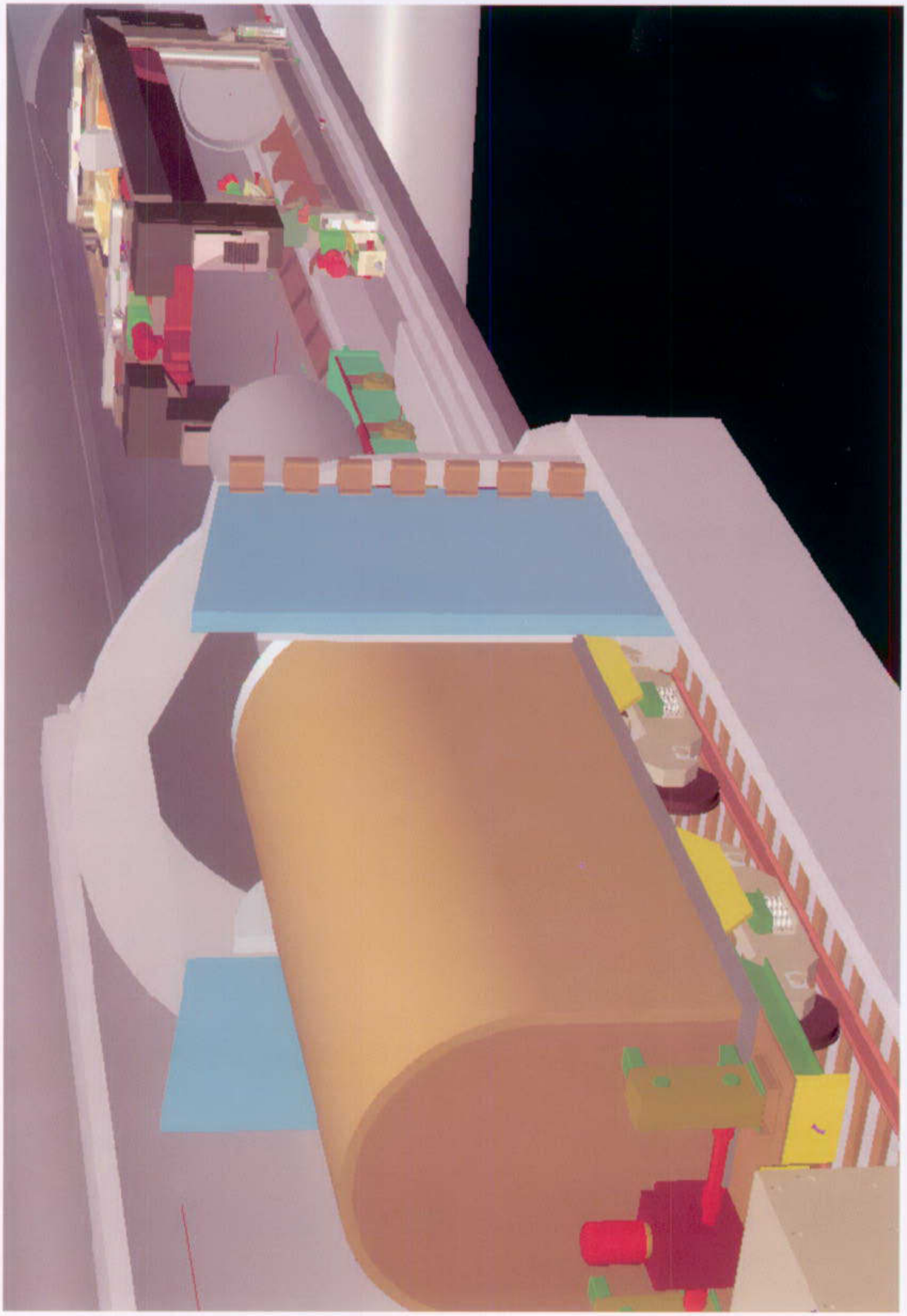

Figure 6-4. Transporter at Emplacement Drift Entrance

nel will receive training in the locations of primary and alternate evacuation routes from their specific workplace to the surface, as well as the locations of the closest refuge chambers as a contingency if fire or smoke blocks the escape route. All personnel will carry, or have close access to, personal self-rescue breathing devices. Trained mine rescue teams will assist with the evacuation of personnel and controlling the fire. There will be two independent subsurface ventilation systems—one for the development side and one for the emplacement side. To escape the effects of a fire, personnel may move through isolation air locks from one ventilation system to the other.

The potential for a subsurface fire of significant duration is low because administrative controls will limit the kinds and amounts of combustible materials allowed in the underground facility without having to post a firewatch. In areas where the potential for fire may be higher, precautionary measures will include placing fire extinguishers on mobile equipment and installing automatic fire suppression equipment at conveyor drive and transfer points. Electrical equipment will be installed in alcoves that are equipped with fire detection and suppression systems.

As with the surface facilities, loss of offsite power is a potential design basis event. Normal subsurface operations will be suspended during a loss of power. Backup power will be provided where required. For example, main ventilation fans, subsurface monitoring, and communications systems are among those systems that must be maintained during a loss of power. In addition to those structures, systems, and components that require backup power, uninterruptible power will also be supplied to critical systems such as computer systems and those monitoring systems that cannot tolerate short-term power loss.

Another potential design basis event is a runaway transporter in the subsurface. The surface-based controllers will be alerted to a potential transporter-related off-normal condition if a loss of control or absence of response is experienced during transport. Visual monitoring and radiation detection systems will also be installed in the subsurface. If an off-normal condition is detected, personnel with radiation detection equipment or remotely operated equipment will be dispatched to gather additional visual and radiation information, depending on radiation levels. A specific response plan will be developed based on the information gathered.

In the event of radiological release in the subsurface, a high-radiation signal will divert the subsurface ventilation system exhaust flow through high-efficiency particulate air filters. This measure will prevent an uncontrolled release of radioactive particulates into the surface environment. As stated previously, personnel or remotely operated equipment will be dispatched to investigate and gather additional data. A specific response plan will be developed.

Mitigation and cleanup systems, including remotely operated cleanup systems, will be designed to operate during off-normal conditions that result in a radiological release. Components of equipment that are important to radiological safety will be redundant and fail-safe. In addition, this equipment will be furnished with standby power and the independent controls required for recovery operations during a given design basis event. Equipment, instruments, lighting, and controls that are required to support waste package recovery will be provided with uninterruptible power supplies. Equipment designs will also consider human factors to minimize the possibility of design basis events being caused by human error. Particular attention will be focused on equipment whose failure could potentially lead to a radiological release.

Operators and maintenance technicians will be certified and periodically retrained to minimize the potential of operator and maintenance errors. Off-normal operating, maintenance, and recovery procedures will be developed and verified. These procedures will be periodically updated, based on operator experience, and reverified.

The repository will be monitored and maintained from the time that the last waste package has been emplaced until the repository is closed. Permanently installed sensors will monitor waste packages, drifts, and the surrounding rock from accessible locations within the perimeter drift and observation (performance confirmation) drifts and will provide the data required for performance confirmation. A remotely operated gantry will be used to investigate conditions within the emplacement drifts to eliminate risk to workers from heat and radiation emanating from the waste packages (see Section 4.2.5).

The accessible drifts not containing waste packages will be routinely inspected and the ground support repaired, as required. If maintenance in an emplacement drift is necessary (e.g., due to rockfall), the drift will be cooled, and the waste packages temporarily relocated to facilitate the repairs.

Closing subsurface openings involves removing underground equipment, preparing the openings to receive backfill, backfilling the openings, and sealing the openings. Unsuitable materials, as well as utilities and support services, as appropriate, will be removed prior to closure. The openings to be backfilled include the main drifts, ventilation shafts, boreholes, and access ramps. The utilities and equipment specifically required for backfilling will be installed before backfilling operations begin. Backfilling will involve obtaining material from the surface stockpile or other source, processing the material to obtain the required particle size, stockpiling the processed material for subsequent loading, and transporting the material below ground for emplacement. The purpose of the backfill is to prevent unauthorized access.

Sealing the repository openings involves preparing the underground openings to receive the seals, obtaining and transferring seal material, and constructing the seals. The VA design assumes that seals will be placed in boreholes, shafts, and ramps only. Backfill will be placed on both sides of each seal. The purpose of sealing the openings is to ensure proper waste containment and repository performance.

Seals for boreholes will be developed to ensure that the boreholes do not become preferential pathways for radionuclide migration. In addition, the borehole seals will limit vertical water flow to less than 1 percent of the vertical water flow through the rock mass within 400 m (1,300 ft) of the perimeter drifts. The borehole seals will also limit air flow, consistent with the air flow constraints for the shaft and ramp seals.

The seals installed in the shafts and ramps will limit the air flow through the sum of all subsurface openings to less than 1 percent of the air flow through the rock mass over the area that extends to 400 m (1,300 ft) beyond the repository perimeter. In addition to sealing the shafts and ramps, the system of seals will be designed to provide sufficient subsurface water storage capacity to accommodate the volume of water that could be retained and allowed to drain into the rock in one year without coming in contact with the waste packages.

Cement-like materials and earthen materials, alone or in combination, can be used for the shaft and ramp seals. Cement-like materials will resist both hydrologic flow and structural loads. The construction sequence for shaft and ramp seals may include grouting the surrounding rock, removing the concrete lining or other artificial support, constructing the seal, grouting the interface zone, and then resuming backfill operations.

Backfilling the emplacement drifts is not included in the VA reference design, but is addressed as an option in Section 5.3.

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7. DESIGN FLEXIBILITY CONSIDERATIONS

From a systems engineering approach, the design of any system should incorporate enough flexibility to accommodate plausible contingencies. Moreover, 10 CFR 60.133(b) requires that the Monitored Geologic Repository be designed so that it has "... sufficient flexibility to allow adjustments where necessary to accommodate specific site conditions identified through in situ monitoring, testing, or excavation." The VA for the Monitored Geologic Repository incorporates such flexibility in design, construction, and anticipated operations.

A number of areas have been identified which could reasonably produce the need for changes in the current design. Such areas include the following: (1) statutory redirection and (2) unanticipated challenges in the areas of construction and operations. Both are discussed in the following sections.

7.1 FLEXIBILITY IN SELECTING REPOSITORY LOCATION AND LAYOUT

Flexibility exists in regard to the selection of the location for the repository host horizon in the unsaturated zone and the capacity of the underground facility.

7.1.1 Flexibility in Capacity

The Nuclear Waste Policy Act of 1982, as amended, directs NRC in its decision to approve the first application for a geologic repository to prohibit the emplacement in the first repository of a quantity of spent nuclear fuel and high-level radioactive waste in excess of 70,000 MTU until such time as a second repository is in operation (Section 114 (d)). This implies that Yucca Mountain could be required to handle more than 70,000 MTU at some future date. Also, the environmental impact statement (EIS) will address the disposal of more than 70,000 MTU at Yucca Mountain. To support the environmental analyses, flexibility is being maintained through the identification of a potentially larger repository emplacement area.

The repository's capacity and its flexibility are dependent on the design thermal loading. Thermal loading, expressed in terms of metric tons of uranium per acre (MTU per acre), determines the areal density at which wastes are spaced in the repository. Design concepts based on "high" thermal loadings, in which the waste packages are spaced more closely, require less area for a given total inventory than "low" thermal loadings, in which wastes are placed farther apart. Therefore, the capacity of any given underground area is a function of thermal loading. The thermal loading strategy and rationale selected for the VA design are discussed in Sections 4.2 and 5.1.3.2.

The VA reference design is based on a thermal loading of 85 MTU/acre, accounting only for the commercial spent nuclear fuel portion of the inventory. The defense high-level radioactive waste and other waste forms generally have low initial heat output and decay much faster than commercial spent nuclear fuel. Therefore, their heat loads are not determinant in the thermal loading. The total area required for emplacement of the 63,000 MTU of commercial spent nuclear fuel is 63,000 MTU divided by 85 MTU/acre, or 741 acres.

The primary emplacement area that is currently being characterized, which encompasses the required 741 acres to accommodate the 63,000 MTU of commercial spent nuclear fuel and 7,000 MTU of other forms of high-level radioactive waste, can be developed into a repository having an upper block, located between the Solitario Canyon fault to the west and the Ghost Dance fault to the east, and a lower block bounded by the Ghost Dance fault on the west and the Imbricate fault zone to the east. In the reference design, only the upper block has been configured for emplacement of the 70,000 MTU at the design thermal loading. However, this block may be expanded significantly to accommodate an increase in the waste inventory. According to the *Repository Subsurface Layout Configuration Analysis*, approximately 1,150 acres of total emplacement area could be developed in the upper block (CRWMS M&O

1997ab, Attachment II, p. 2). Full development of the lower block could provide approximately 400 additional acres (CRWMS M&O 1997ab, Attachment II, p. 2). These two areas combined yield a total emplacement area of approximately 1,550 acres or slightly more than twice the area currently needed. Hence, the primary emplacement area provides significant flexibility in the area available for emplacement.

There are other potential emplacement areas outside the primary area. No site characterization activities have focused on these areas, so only limited data are available. However, using surface fault mapping, outcrop information, and data from the limited drilling that has been done in these areas, it is possible to estimate the size of potentially suitable emplacement blocks that are available to the west of the primary area. While no specific references are available, the total potential area available for underground development in the unsaturated zone is estimated to be more than 2,000 acres. Significant additional site characterization work would be required to confirm whether these areas are suitable for waste emplacement. This flexibility in designating the 741 acres required for the disposal of 70,000 MTU out of an available area of between 1,550 and 2,000 acres translates into added flexibility in dealing with any poor ground conditions (see the following section) and other contingencies that may be experienced in the emplacement drifts.

As noted above, the repository's capacity is dependent upon thermal loading. And since the thermal loading is dependent upon the size and heat load of individual waste packages, this translates into flexibility with regard to waste package size and thermal output. Alternative thermal loading strategies and waste package designs are discussed in Section 8.

7.1.2 Flexibility in Accounting for Unsuitable Ground Conditions in Emplacement Drifts

The emplaced waste will be loaded into approximately 100 emplacement drifts. An additional 5 drifts will serve non-emplacement functions. Unsuitable ground conditions could be encountered during development of some of the emplacement drifts. Only drifts with adequate structural integrity and ground support will be used for waste emplacement. In the event that it is determined that a drift is unacceptable, the availability of excess acreage for development of additional emplacement drifts provides assurance that the entire 70,000 MTU could be disposed of in the underground facility. The VA reference design includes 100 emplacement drifts, 5 non-emplacement drifts, and 15 contingency emplacement drifts at the south end of the emplacement block, as shown on Figure 7-1.

7.2 FLEXIBILITY IN DESIGN, CONSTRUCTION, AND OPERATIONS

Flexibility is incorporated into design, construction, and operation activities to ensure that the Monitored Geologic Repository can meet its expected performance.

7.2.1 Flexibility in Design

Section 8 discusses major alternative designs currently under evaluation. Such major alternatives include smaller waste package sizes and drifts, varying emplacement thermal loadings, and other considerations. Section 5.3 identifies options currently under evaluation that may enhance the performance of the engineered barrier system in the reference design. Site conditions identified through in situ monitoring, testing, or excavation might require that one or more of the major alternatives and/or engineered barrier system options under evaluation be incorporated into a revised design. The current approach to design would facilitate any such necessary modifications to the reference design.

In accordance with its 1995 Notice of Intent (DOE 1995a), DOE intends to encourage maximum participation by the commercial sector in waste pickup at waste generator sites and transportation of such wastes to the repository. Spent nuclear fuel is expected to be received at the repository in small-capacity transportation casks that require transfer of individual spent nuclear fuel assemblies into dis-

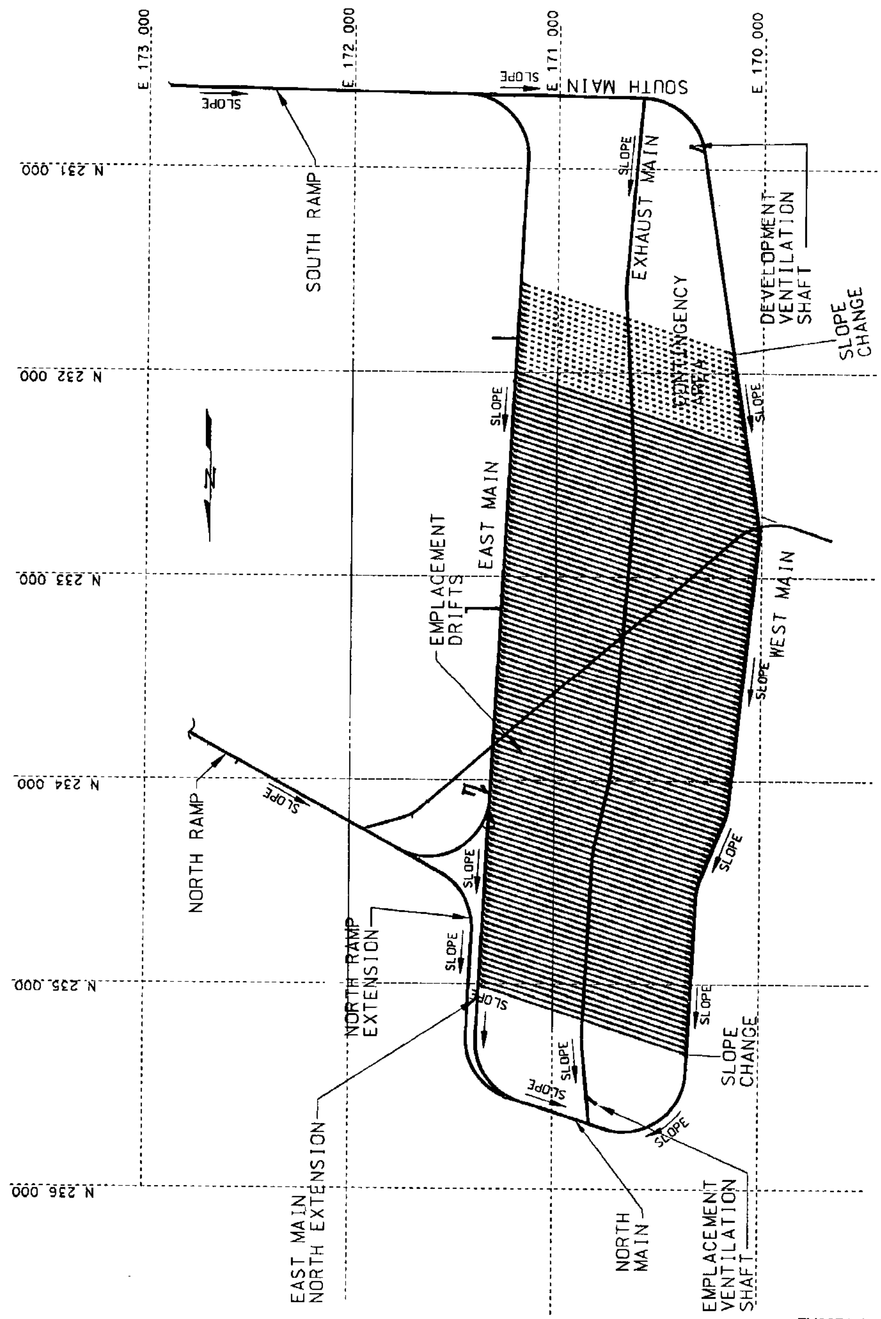

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Figure 7-1. Subsurface Repository

posal containers. Spent nuclear fuel is also expected to be received in nondisposable canisters that require the canisters to be cut open and the individual fuel assemblies transferred, one at a time, into the disposal containers. Spent nuclear fuel is also expected to be received in canisters approved for disposal. Such canisters will be transferred in a dry environment directly into disposal containers. Thus, while the modes of spent nuclear fuel receipt have been identified, the combinations, that is, how much fuel will be received over the repository operating lifetime requiring individual assembly transfer versus canister transfer, cannot be identified. Therefore, the surface facility design maintains the flexibility to receive all modes of receipt in broad combinations by including wet and dry transfer capabilities. Moreover, the incorporation of a pool transfer operation into the surface facility design for receipt and intermediate underwater transfer of individual spent nuclear fuel assemblies also provides flexibility with regard to receiving and handling future generations of differently configured transportation casks. The incorporation of a pool into the design also provides added flexibility in addressing spent nuclear fuel and/or cask recovery operations and in carrying out cask decontamination activities.

7.2.2 Flexibility for Extended Monitoring Period

Incorporation of a robust ground control system into the underground design helps ensure that main and emplacement drifts will hold their desired configuration for a period of up to 300 years with only minimal maintenance. Periodic manual inspections of the main drifts will determine the conditions inside and any needed repairs can be accommodated. Ongoing, remotely operated performance confirmation activities will communicate the conditions inside the emplacement drifts where personnel access is prohibited. Repairs to an emplacement drift can be accommodated by cooling the drift using the ventilation system followed by removal of the emplaced waste packages using the emplacement equipment. Packages removed are placed in one of two empty emplacement drifts ("parking" drifts) maintained for this purpose. Personnel can then enter the drift and make needed repairs. The process would then be reversed and the packages would be moved back into the original drift.

7.2.3 Flexibility in Emplacement Schedule

The emplacement schedule must be maintained despite construction delays. The capacity to maintain this flexibility is achieved by having the capacity to excavate emplacement drifts faster than they are filled by emplacement operations. The current design calls for a single tunnel boring machine to excavate the emplacement drifts. At the projected advancement rates, a single machine will be able to stay ahead of emplacement operations. A second tunnel boring machine will excavate the performance confirmation drifts. However, this second machine can be made available to excavate emplacement drifts should the need arise.

7.2.4 Flexibility in Emplacement Operations

The design must accommodate an increased emplacement rate, if needed, to handle short-term surges in surface waste handling operations. The YMP internal system description document for the waste handling system *Waste Emplacement System Design Description* (CRWMS M&O 1998n) requires that the system be capable of handling a surge of 20 percent in excess of the nominal rate for a period of up to 4 months. The cycle times for the emplacement operation have been developed so that a single transporter train (made up of the waste package transporter and two locomotives, see Section 4.2) can handle the nominal emplacement rate in less than two shifts. If the emplacement rate must be increased, part of the third shift, normally reserved for maintenance, can be used to continue emplacement operations. If a higher rate is needed, a second train and crew can operate simultaneously with the first with minimal interference. The current design includes the use of multiple emplacement gantries, which allows some selectivity in the placement of waste packages. With multiple gantries available, only the transport portion of the emplacement cycle will require adjustment if the emplacement rate is increased.

8. MAJOR DESIGN ALTERNATIVES

8.1 INTRODUCTION

DOE initiated an effort to ensure that an appropriate and comprehensive range of alternative design features and concepts is examined before selecting the reference design to support site recommendation and the subsequent LA. Such an evaluation is an appropriate precursor to submittal of the LA to ensure that reasonably different approaches have been considered and because NRC regulations require a comparative evaluation of alternatives to major design features that are important to waste isolation. To ensure that the EIS evaluates a reasonable range of alternatives that represents the full spectrum of potential environmental impacts, the EIS will assess the significance of the impacts associated with the VA reference design, the VA reference design with options, and alternative features and design concepts such as those described in this section.

To identify potential repository design alternatives, DOE conducted a series of evaluations. The intent was to ensure that a broad suite of alternative design features and repository design concepts were considered.

The evaluation process resulted in a list of performance, operational, and safety criteria that was used to guide the development of potential alternative design features and concepts. A number of potential performance-enhancing design features were then developed to address the criteria and were grouped into five categories. Each of the alternative design features was examined to determine whether it was independent of or dependent on a specific layout.

The independent design features are those components of the repository that could affect performance regardless of the repository layout. For example, the ability to assess the effects that different waste package designs have on performance is not constrained by the layout of the repository. Likewise, rod consolidation and the use of fillers in the waste package are not constrained by the layout of the repository. Therefore, these independent design features are being evaluated in separate studies.

The performance enhancement potential of layout-dependent design features, however, cannot be evaluated unless they are applied to a specific layout. For example, reducing the design thermal load of the emplacement drift would likely require more drifts, smaller waste packages, or a ventilation scheme different from that presented in the VA reference design. This design layout could also require greater waste handling capacity at the surface than presently called for in the VA reference design. For these design features that are not independent of the design layout, a small set of alternative design concept layouts that would enable evaluation the design features that are more dependent on the design layout were identified.

To evaluate these layout-dependent design features, five alternative design concepts were subsequently developed. Each of these design concepts is based on a surface and/or subsurface repository layout that is significantly different from the VA reference design. These five alternative layouts are described in this section and are referred to as the alternative design concepts. Design studies are underway for these alternative layouts to assess their potential for performance enhancement. Costs associated with these potential design alternative concepts are not included in the VA cost estimates.

The design features and alternative design concepts described in this section have been developed to the level to identify design studies needed to support the selection of the initial site recommendation and subsequent LA design. The information in this section is intended to help readers understand the plans for design work that will be completed between the VA and LA, and provides a basis to assess the nature of the design work that will be undertaken to develop the design that could eventually support site recommendation and be included in the LA.

Design studies supporting the development and evaluation of design options, design features, and alternative design concepts will allow DOE to select a design to be carried forward to support site recommendation and the LA. This selection will be based on strategies for licensing approach, design margin, and defense in depth, as well as a strategy for addressing uncertainty. In work that is currently underway and that will continue into fiscal year 1999, these options, design features, and alternatives will be more fully developed and their performance and projected cost will be evaluated. The design selected could be closely related to the VA reference design or could be an enhanced version of that design. Likewise, the design could be one of the VA alternative design concepts or an as yet not developed design concept that takes advantage of the performance potential of one or more design features.

8.2 VIABILITY ASSESSMENT REPOSITORY DESIGN ALTERNATIVES SELECTION PROCESS

To support preparation of the VA, a series of evaluations were conducted to identify potential design features and alternative design concepts that could be included in the VA. The process involved the development of criteria that could be used to identify design features and alternative design concepts.

8.2.1 Development of Criteria

Criteria selected from the design criteria for the geological repository operations area listed in 10 CFR 60 were used as the initial list. The initial list of criteria encompassed NRC-specified minimum requirements for the principal design criteria for the geologic repository operations area. While these design criteria are not necessarily sufficient to demonstrate compliance with the 10 CFR 60 performance objectives, they clearly are a comprehensive set of requirements related to design features.

Initially emphasis was placed on the postclosure performance-related design criteria of 10 CFR 60. A primary factor for this emphasis was that NRC required comparative evaluation of alternative design features that potentially could provide longer containment and isolation of radionuclides. As the criteria were used, the need for an additional criterion related to worker and operational safety became clear. Also, care was taken to ensure that the criteria encompassed the following:

- Operational ease
- Explicit consideration of prevention as well as mitigation of releases
- Preclosure performance monitoring, of important postclosure-related behaviors

The criteria that addressed the potential for enhanced performance were related to the following:

- Orientation, geometry, layout, and depth of the facility and related barriers that contribute to isolation
- Safe operation of underground openings and maintaining the capability to retrieve the waste
- Reduction of the potential for deleterious rock movement or fracturing
- Engineered barriers
- Thermal load
- Waste package design
- Waste form criteria
- Other radioactive wastes
- Worker and operational safety
- Monitoring postclosure-related behavior

8.2.2 Development of Alternatives Categories and Identification of Design Features

The criteria listed above are somewhat interrelated and were grouped into the five categories identified in Table 8-1 to facilitate discussion. The approach to identify categories of alternatives was also used to introduce structure in the process of selecting alternative design concepts, and to limit the tendency to identify design solutions at the early stages of the selection process.

The alternatives categories and associated sets of design features and characteristics reflect experience, as well as suggestions offered in external forums. The five alternatives categories and the list of design features shown in Table 8-2 were identified. Category 1 comprises features and characteristics that are related to containment within the engineered barrier system. Category 2 comprises features and characteristics related to other engineered enhancements. Category 3 comprises those design features and characteristics related to the integrated effects of thermal loading. Categories 4 and 5 are more closely related to operations or monitoring of the system; these categories comprise features and characteristics that are related to waste package production and emplacement operations and deferred closure.

The categories of Table 8-2 are intended to be general groupings of the design features identified. Specific design features may be important to categories other than the one in which they are listed. The relationships between the attributes of the repository safety strategy, the principal factors of the VA design and its options, and the design features from the alternatives studies are illustrated in Table 8-3.

The design features that were considered to be independent of specific alternative design concepts were next identified. These features or characteristics could affect performance in a manner that could be applied to any design alternative and, conceivably, result in performance enhancements. These independent design features are listed in Table 8-4. For these independent features, design studies have begun and will investigate the potential for performance enhancement. Section 3.2 of Volume 4 outlines the approach for completing studies of these features.

The design features identified in Table 8-2 are described in the following list, along with a general indication of the potential for enhancing design performance for those features directly related to the repository safety strategy attributes:

- **Two corrosion-resistant materials**–The VA waste package design considers a single corrosion-resistant barrier with a surrounding, thick, mild steel barrier to provide strength. A variation of this design is to add a second corrosion-resistant barrier. This design could provide defense in depth if the second corrosion-resistant barrier is

Table 8-1. Performance-Related Criteria Used to Develop Design Features

Alternatives Categories	Performance Related Criteria
Containment Within the Engineered Barrier System	Engineered Barriers
	Waste Package
	Waste Form Criteria
	Other Radioactive Wastes
Other Engineered Enhancements	Orientation, Geometry, Layout, and Depth of the Underground Facility, and Facility Related Engineered Barriers that Contribute to Containment and Isolation
	Reduce Potential for Deleterious Rock Movement or Fracturing Around Openings
Integrated Effects of Thermal Loading	Thermal Load
	Underground Facility Ventilation
Waste Package Production and Emplacement Operations	Worker and Operational Safety
	Monitoring Important Postclosure Related Behavior
Deferred Closure	Safe Operation of Underground Openings and Retrievability Option Maintained

Table 8-2. Design Features for Alternatives Categories

Category 1–Containment Within the Engineered Barrier System	
Waste Package Materials	One Corrosion-Resistant Material or Two Corrosion-Resistant Materials
	Ceramics
Barriers	Drip Shield
	Richards' Barrier
	Diffusive Barrier or Getter Under the Waste Package
	Backfill
Internals	Canisterized Assemblies
	Additives/Fillers
Emplacement Mode	Angled (herringbone) Horizontal Ceramic-Lined Borehole
	Vertical Emplacement
Category 2–Other Engineered Enhancements	
Metal-Lined Drift	
Unlined Drift	
Near-Field Rock Treatment During Construction	
Surface Modification	Engineered Fill
	Drainage
Category 3–Integrated Effects of Thermal Loading	
Waste Package Size	
Thermal Load	
Aging (Pre-Emplacement)	
Blending (for Thermal or Criticality Considerations)	
Ventilation (Preclosure and Postclosure)	
Waste Package Spacing (e.g., Line Load)	
Temperature Limits (Cladding Credit, Zeolites, Rock Wall and Surface Temperatures)	
Rod Consolidation	
Backfill (Timing)	
Drift Spacing	
Drift Diameter	
Category 4–Waste Package Production and Emplacement Operations	
Waste Handling Building Waste Package Production Line Capacity and Throughput	
Waste Package Closure/Shield Material Thickness Inter-Relationships	
Waste Package Fabrication Processes	
Emplacement Mode	
Accessibility to Waste Packages (Shielding for Personnel Access; Self Shielding)	
Category 5–Deferred Closure	
Underground Features, Ground Support and Maintenance	
Timing of Repository Closure	

independent of the first (e.g., made of a different metal). This approach, if employed, could be highly important to postclosure performance.

- **Ceramic coating**–Ceramic coating on the waste package provides an impermeable barrier that could last millions of years under repository conditions. Such a barrier could have a significant effect on performance, as

Table 8-3. Relationships Among Elements*

Repository Safety Strategy Attributes	Principal Factors for VA Reference Design and Options	Design Features from Alternatives Study
Water Contacting Waste Package	Precipitation and Infiltration into the Mountain	Surface Modification (Engineered Fill, Drainage)
	Percolation to Depth	
	Seepage into Drifts	Metal Lined Drift, Ceramic Lined Emplacement Borehole, Near-Field Rock Treatment
	Effects of Heat and Excavation on Flow	Thermal Load
	Dripping onto Waste Package	
	Humidity and Temperature at Waste Package	Temperature Limits, Waste Package Size/Spacing, Aging, Blending, Rod Consolidation, Ventilation, Drift Size/Diameter
	Diversion by Drip Shields or Backfill	Drip Shield, Richards' Barrier, Backfill
Waste Package Lifetime	Chemistry on Waste Package	
	Integrity of Outer Carbon Steel Waste Package Barrier	
	Integrity of Inner Corrosion-Resistant Waste Package Barrier	One or Two Corrosion Resistant Materials
	Integrity of Ceramic Waste Package Coatings	Ceramic Coating
Mobilization Rate of Radionuclides	Seepage into Waste Package	Additives, Filler
	Integrity of Spent Nuclear Fuel Cladding	
	Dissolution of Uranium Oxide and Glass Waste Forms	
	Neptunium Solubility	
	Formation of Radionuclide-Bearing Colloids	Diffusive Barrier, Getters
	Transport Through and Out of Waste Package	
Concentration of Radionuclides in Groundwater	Transport Through the Unsaturated Zone	
	Flow and Transport in the Saturated Zone	
	Dilution from Pumping	
	Biosphere Dilution	

* Relationships among the repository safety strategy, the principal factors for the VA reference design and options, and the design features from this alternatives study. The postclosure repository safety strategy does not address design features related to operations (canistered assemblies, emplacement mode, unlined drifts, production line capacity, waste package fabrication, emplacement mode, assessibility).

long as it is intact, and could provide redundancy to a corrosion-resistant metal base under the coating. This approach could be highly important to performance.

- **Drip shield and backfill**–A drip shield placed above the waste package could divert water away from the waste. Backfill placed under and above the drip shield could protect it from rockfall and ground shaking due to seismic activity. In addition, backfill could inhibit diffusive flow below the drip shield. This combination could limit the water that could contact the waste packages and could provide redundancy to the waste package containment barriers. Timing of backfill emplacement is an important consideration, as backfill would affect the thermal conductivity of the engineered system. The performance assessment sensitivity studies (Volume 3, Section 5.3) indicate that this effect could be highly important to postclosure performance.

- **Richards' barrier**–A Richards' barrier can divert water from the waste package as well. This barrier takes advantage of the differences in conductivity of materials that are

Table 8-4. Independent Design Features and Characteristics for Alternatives

Design Feature
Aging (Pre-Emplacement) of Waste
Blending of Waste (for Thermal or Criticality Considerations)
Waste Handling Building Production Lines
Continuous Ventilation
Rod Consolidation
Timing of Repository Closure
Underground Features and Ground Support (Maintained and Not Maintained)
Drift Diameter
Waste Package Shielding
Waste Package Corrosion Resistant Materials (Metal and Ceramic)
Barriers • Richards' Barrier • Diffusive Barrier or • Getter Under the Waste Package
Internals • Canistered Assemblies • Additives and Fillers
Ground Support • Metal-lined Drift • Unlined Drift
Near-Field Rock Treatment During Construction
Surface Modification • Engineered Fill • Drainage

not fully saturated. The barrier is composed of two layers, the upper layer having substantially greater conductivity than the lower when they are both at the same moisture potential. The interface of these two layers slopes, and measurements show this barrier could effectively divert flow at the interface for low seepage fluxes. This combination could divert water away from the waste package and could provide redundancy to the waste package containment barriers. The performance assessment sensitivity studies indicate that this barrier could be highly important to performance, if it were effective.

- **Engineered diffusive barrier–**Backfill or other materials placed underneath the waste packages could retard transport of radionuclides released from breached waste packages. Performance assessments indicate that the drift inverts could have some effect on performance and a specially tailored transport barrier using a chemical getter likely could do better. Such a barrier could provide redundancy to the natural unsaturated and saturated zone barriers at the site. Performance assessment sensitivity studies suggest this barrier could be moderately important to performance.

- **Waste package filler**–A filler in the waste package could limit the flow of water that seeps into the waste package and the mobilization and transport of radionuclides contacted by water. Thus, release of radionuclides from breached waste packages could be significantly reduced. This barrier could provide redundancy with the cladding and waste form constraints on the radionuclide mobilization and release rate. Based on the performance assessment sensitivity studies of such effects, this approach could be moderately important to postclosure performance.

- **Canistered assemblies**–Placing of spent nuclear fuel assemblies in canisters before inserting them into the waste package could provide an additional barrier and limit mobilization of radionuclides in breached waste packages. Canisters involving Zircaloy or other corrosion-resistant material could increase confidence in the performance of such waste packages by increasing the time to waste package breach. The performance assessment sensitivities indicate that this effect could be highly important to postclosure performance.

- **Horizontal or vertical borehole emplacement–**Emplacement of waste in small waste packages that are, in turn, placed in horizontal or vertical boreholes would facilitate emplacement and recovery operations and could permit inspection of the emplacement drifts by allowing direct human access in the emplacement drifts during the operations period. Horizontal borehole emplacement could also increase confidence by limiting contact of water with the waste package through the use of borehole linings or by angling the boreholes to enhance drainage of water away from the waste package. Vertical borehole emplacement could also increase confidence by enhancing drainage away from the waste package and by providing a decreased cross-sectional area for contact by water. Because of the relative importance of these effects to performance, this approach could be moderately important to postclosure performance if it were to be adopted. The gains from this approach would have to be measured against the loss of those from the large, robust, drift-emplaced waste packages.

- **Metal-lined drift–**The emplacement drifts could be lined with steel sets and steel lagging to limit the introduction of cementitious materials into the drift environment. Limiting the amount of cementitious material in the drift has the potential to lessen potential effects on the pH and hence the system chemistry in the early postclosure time frame. This approach has the potential to be moderately important to performance.

- **Unlined drift–**An unlined drift could be appropriate in a low-stress situation in competent rock and could result in significant cost savings. The potential for rockfall, which could be a significant initiating event for waste package failure, must be carefully evaluated for unlined emplacement drifts.

- **Near-field rock treatment during construction–**The rock face of the drift wall could be treated (e.g., with low permeability grout) to limit seepage into the drift. This could increase confidence in limited water contacting the waste package. Because of the relative importance of percolation and seepage to postclosure performance, this approach is assumed to be moderately important to performance. There is considerable experience with such treatment. Grouts of different types have been successfully used to control water in mines for many years.

- **Surface modification–**Net infiltration into the mountain could be significantly decreased if the surface of the mountain were modified. Alluvium significantly reduces net infiltration into the ground and percolation to depth in the flats away from the mountain. Analyses for Jackass Flats indicate negligible net infiltration (Volume 1, Section 2.2.3). The performance of the mountain could be modified through a thick layer of engineered fill applied to the surface at this site. Likewise, facilities for drainage of water to enhance runoff could be designed. Because these effects could potentially eliminate net infiltration at the site, the potential importance to performance could be high.

- **Thermal loading and temperature limits–**The current thermal loading for the repository design enables emplacement of the waste into a contiguous region of rock and results in a high thermal load. Postclosure performance for this thermal loading was evaluated and considered to be adequate. However, spreading the waste over a wider area could result in lower thermal loading and reduced temperatures. This reduction could result in lower corrosion rates of waste package barriers during the thermal period. This effect could be significant to postclosure performance. The VA reference design addresses a number of thermal limits or goals selected to limit effects detrimental to waste isolation, impacts on the surface environment, prevent thermally induced rock failure, and provide an appropriate operational environment. Relaxing one or more of these thermal limits would enable different approaches to subsurface design, such as higher thermal loading designed to prevent water from contacting the waste. Thus, different approaches to the thermal limits, if employed, could be highly important to performance.

- **Waste package size, waste package spacing, drift diameter, and drift spacing–** Waste package size, waste package spacing, drift diameter, and drift spacing are important parameters related to thermal loading. Drift diameter is most closely related to the thermal limits; as drift diameters become smaller, the distance from the package to the rock decreases, with a concomitant increase in temperature of the rock surface and waste package. Waste package size, waste package spacing and drift spacing affect the areal mass thermal loading. Decreasing the waste package size allows development of a lessened thermal loading scheme. Decreasing the waste package spacing leads to a nearly continuous heat source down the length of the emplacement drifts. This approach provides for more intense thermal environments near the emplacement drifts and, with greater drift spacings, could lead to a more benign environment in the pillars between the drifts. Analyses indicate that this approach could enhance dryout of the rock close to the waste packages. The analyses also indicate that the time before condensate returns could increase and that the drainage of condensate would likely occur through the pillars rather than through the emplacement drifts. Thus, line loading could decrease the amount of water that could contact the waste package. The performance assessment sensitivity studies indicate that this effect could be important to postclosure performance.

- **Ventilation–**The ventilation system for the Exploratory Studies Facility currently removes significant quantities of water from the host rock. The drying front has extended several meters into the rock, and the effect of the drying is felt, to some degree, tens of meters away from the drift already. Ventilation during the operational phase of the repository could remove considerable water from the system, as well as reduce temperatures. Continued ventilation during the postclosure phase could be effective in removal of heat as well as moisture as it returns as condensate or as flow paths are reestablished. This could minimize the uncertainties associated with mobilization of pore water by the waste-generated heat and possible return of condensate later. The performance assessment sensitivity studies indicate that the effects of heat on the timing and the amount of flow in the host rock are moderately important to performance. For this reason, it is likely that the effects of extended ventilation could be moderately important to postclosure performance.

- **Pre-emplacement aging, waste blending, and rod consolidation–**Pre-emplacement aging, waste blending, and rod consolidation provide mechanisms that are important to managing the thermal output of a waste package. By aging the waste on the surface prior to emplacement, it could be possible to emplace wastes when the thermal decay curve was less steep, resulting in less variable thermal output of the waste packages. Blending the waste, or leveling, could also result in more uniform temperatures and thermal decay characteristics of the waste packages. While beneficial to a thermal management scheme, both pre-emplacement aging and blending could require additional surface facilities. Rod consolidation also has potential benefits related to emplacement. A higher density of fuel rods could be emplaced in a waste package and could result in higher waste package temperatures, should that be the goal of the thermal management scheme, as well as a smaller number of waste packages. The performance assessment sensitivity studies suggest that managing the thermal output of a waste package could be moderately important to postclosure performance.

- **Waste package fabrication processes–** Waste package fabrication processes together with Waste Handling Building waste package production line capacity and throughput, and waste package closure are surface facility-related design features. One aspect of the production line process is the alternative feature related to the use of wet or dry transfer of the production line process is the alternative feature related to the use of wet or dry transfer systems in unloading and loading containers. Many of the design features examined suggest the need for a smaller waste package size. This could result in the need for additional surface facility production capability, likely manifested as a greater number of production lines. Design alternative concepts that address accessibility to waste packages through the use of shielding could also have an impact on the waste package fabrication processes.

- **Accessibility to waste packages–**The VA reference design uses remote handling operations for waste packages in the emplacement drifts. An alternative that uses self-shielded waste packages would allow personnel access to the emplacement drifts. Such access could be important to performance confirmation tests and studies by allowing visual inspection of the waste packages or direct access to performance confirmation instrumentation.

- **Timing of closure and ground support maintenance–**The VA reference design is predicated on closure of the facility in approximately 100 years. Implementing a comprehensive performance monitoring program could lead to a policy of leaving the repository open for a much longer period of time, conceivably as much as 300 years. Leaving the repository open for such a period of time could place additional requirements on maintenance of the underground features and ground support. It is possible that beyond this period of time a significant repair to the underground facility would have to be undertaken.

8.2.3 Development of Alternative Design Concepts

Table 8-4 presented a listing of those design features that were independent of design layout. This is a subset of the design features indicated in Table 8-2. The remaining design features are more dependent on a specific design layout. To realize the potential performance enhancement attainable by these design features, a specific layout must be considered. For the VA, appropriate design layouts that were different enough from the VA design to merit treatment as alternative design concepts were sought. The design features that depend on a specific design layout were aggregated to associate those features with related abilities to enhance performance. The aggregated design features subsequently identified are summarized as follows:

- **Thermal loading**–Dictates area requirements, drift spacing, impact on zeolites, ground surface temperature

- **Near-field thermal limits (rock wall temperature)**–Dictates/influences waste package size, cladding temperature, drift diameter, waste package spacing, (e.g. point load/line load)

- **Continuous ventilation**–Dictates drift layout, drift diameter, drift spacing

- **Waste emplacement mode**–Dictates/influences waste package size, waste package arrangements/spacing, drift diameter

For these alternative design layouts, design studies will continue to investigate the potential for performance enhancement. These studies will interface with the studies of the independent design features to ensure that performance enhancements that are associated with the independent design features are also considered for the alternative design layouts. Section 3.2 of Volume 4 outlines the approach for completing studies of these features.

Next, integrated design concepts and pre-conceptual design information for a number of feature-specific alternative design concepts were developed. The logic to this approach was that the independent features generally could be added to any of the design concepts and likely could enhance performance. Studies of the potential for performance enhancement related to an independent design feature will examine the potential for performance enhancement in multiple design approaches. For those design features that are not independent of the design layout, a small set of alternative design concept layouts that would enable evaluation the design features that are more dependent on the design layout were identified.

The following text describes alternative design concepts that were considered for each of the five alternatives categories.

8.2.3.1 Category 1–Containment in the Engineered Barrier System

The following alternative design concepts for Category 1 were addressed:

- The first alternative is essentially the VA reference design, except that two corrosion-resistant materials are used for the waste package; the two materials considered are Alloy 22 and titanium.

- The second alternative has the additional characteristic of maintaining rock wall temperatures below the temperatures specified in the VA reference design.

8.2.3.2 Category 2–Other Engineered Enhancements

The following alternative design concepts for Category 2 were addressed:

- The first alternative is based on the VA designs for the engineered barrier system and the waste package, with two exceptions: for the subsurface design, near-field rock treatment that could potentially enhance postclosure performance is considered, and for the surface design, engineered enhancements such as soil treatment or alluvial drainage are considered.

- The second alternative concept examines a waste-specific containment design concept. In this concept, the different wastes are segregated in subsurface areas specifically selected to best match performance characteristics suited to disposal of that specific waste type. The engineered barrier system is also unique to the waste type; it builds from the VA reference design and incorporates the use of titanium.

8.2.3.3 Category 3–Integrated Effects of Thermal Loading

The following alternative design concepts for Category 3 were addressed, each of which uses a thermal load of 25 MTU/acre:

- The first alternative uses a large waste package, containing either 21 pressurized-water reactor elements or 44 boiling-water reactor elements, and a rock temperature less than 200°C (392°F).

- The second alternative design concept uses a smaller waste package, probably with less than 12 pressurized-water reactor or 24 boiling-water reactor elements, and a rock temperature of less than 100°C (212°F).

- The third alternative also uses the smaller waste package design and lower temperature limits. However, it also incorporates a smaller, emplacement drift (3 m [9.8 ft] in diameter) with no concrete in the support system.

- The fourth alternative design concept takes advantage of preclosure and postclosure ventilation to moderate thermal effects.

8.2.3.4 Category 4–Waste Package Production and Emplacement Operations

The following alternative design concepts for Category 4 were addressed:

- The first alternative design concept is based on the VA reference design for thermal loading and the engineered barrier system; however, it also uses a self-shielded waste package containing up to 12 pressurized-water reactor or 24 boiling-water reactor elements.

- The second alternative design in this category investigates a smaller self-shielded waste package, which contains up to five pressurized-water reactor or nine boiling-water reactor elements in a smaller-diameter drift with a thermal load of 25 MTU/acre.

- The third alternative also uses a 25 MTU/acre thermal load and small waste packages, containing up to five pressurized-water reactor or nine boiling-water reactor elements. In this alternative, however, the waste packages are emplaced in either vertical or horizontal boreholes, which could be either unlined or lined with metal or ceramic linings.

- The fourth alternative design concept involves emplacing a small waste package in a trench in the floor of the drift; a shield would cover the trench.

8.2.3.5 Category 5–Deferred Closure

For Category 5, a single alternative design concept was examined. This concept is similar to the VA reference design, with the addition of a 300-year maintainable ground support system.

8.2.4 Evaluation and Selection of Alternative Design Concepts

After considering the 13 alternative design concepts described in this section, a subset of these alternative design concepts was selected as likely candidates for alternative design concepts to be considered before selecting the site recommendation and the LA reference design. Generally, paired comparisons or elimination were used to select the subset of five alternative design concepts that are described in the VA; that selection process is described in the following paragraphs. Elimination from consideration for development as part of a specific alternative design concept does not mean that the feature will not be evaluated for its potential for enhancement as an independent design feature.

8.2.4.1 Category 1–Containment in the Engineered Barrier System

The two alternative design concepts that combined the design features in Category 1 were compared and evaluated. These two alternatives incorporate waste package designs and materials different from the VA reference design. Different waste package materials can be evaluated independently. The difference between the two alternative design concepts lies in pursuing lower temperature solutions than the VA reference design temperature constraint on the drift walls; this design can also be evaluated independently. It was therefore concluded that the features related to containment in the engineered barrier system could be independently evaluated; neither of these design features were retained for further evaluation as alternative design concepts. However, the use of two corrosion-resistant materials for the waste package will be evaluated in a separate design study.

8.2.4.2 Category 2–Other Engineered Enhancements

Next, the two alternative design concepts developed for Category 2 were compared and evaluated. The distinguishing features of the first alternative, surface modifications and near-field rock treatment, can be independently evaluated, so this alternative concept was not retained for further consideration as an alternative design concept. However the merits of these features will be evaluated in a separate study. The second alternative design concept employs a significantly different emplacement concept which calls for segregated waste areas. As such, the waste-specific containment design was retained for further evaluation as an alternative design concept.

8.2.4.3 Category 3–Integrated Effects of Thermal Loading

The four Category 3 alternative design concepts were compared and evaluated. The first alternative design in this category, which features large waste packages and rock temperatures less than 200°C (392°F), was compared to the second alternative, which features smaller waste packages. The second alternative was retained for consideration as an alternative design concept not only because it includes a low thermal load, but also because it has lower near-field rock temperatures (less than 100°C or 212°F).

The second alternative was then compared to the third, which has a smaller drift diameter and an unlined and/or no-concrete drift design. Because these two components can be evaluated as independent design features, the third alternative was eliminated from further consideration as an alternative design concept. However, the second alternative, *low thermal load design*, was retained.

The second and the fourth alternative design concepts were evaluated and compared. The fourth design concept, which takes advantage of preclosure and postclosure ventilation to moderate thermal effects, calls for an underground layout that is significantly different from the VA reference design because of the ventilation design. The *continuous ventilation design* was therefore retained as an alternative design concept. The use of smaller drifts will be evaluated in a separate design study.

8.2.4.4 Category 4–Waste Package Production and Emplacement Operations

The four alternative design concepts combining the Category 4 features were compared and evaluated. The first two alternatives were compared to the VA design. Both alternatives involve the use of shielded waste packages, the first at high thermal load and the second at low thermal load. The low thermal load alternative could also employ smaller drifts. It was concluded that the design with the lower thermal load was more likely to be feasible. However, these individual features will require evaluation, so these two alternatives were combined into a single alternative, *enhanced access design*, which was retained for further consideration as an alternative design concept.

The third and fourth Category 4 alternatives involve various waste emplacement technologies for individual packages. The third alternative calls for the waste packages to be emplaced in either vertical or horizontal boreholes that could be either unlined or lined with metal or ceramic linings. The fourth alternative involves emplacing a small waste package in the trench floor. Both of these alternatives require waste emplacement modes, repository layout, and drift designs that are fundamentally different from the VA reference design. Therefore, it was decided to carry these two concepts as a single alternative design concept, *modified waste emplacement mode design.*

8.2.4.5 Category 5–Deferred Closure

The single alternative design concept that combined the Category 5 design features was evaluated for possible retention. Compared to the VA reference design, the extended life concept (up to as much as 300 years) does not dictate a significantly different design and can be evaluated independently, so the deferred closure design alternative was not retained for further evaluation as an alternative design concept. However, the 300-year maintainable ground support system will be evaluated in a separate design study.

8.2.5 Selection of Alternative Design Concepts

Using the process described above, 5 alternative design concepts were selected from the 13 alternatives originally developed. These five alternatives capture the features requiring the alternative design concepts (layout) listed in this section and vary significantly from the VA reference design as described below:

- **Waste-specific containment design**–Each waste type would be in a container uniquely designed for its characteristics. Waste would be segregated in specific areas in the underground, and the emplacement drifts would be designed to promote long-term survivability of the container type. The surface facility design would handle a number of different container types.

- **Low thermal load design**–The emplacement scheme limits the emplacement drift rock temperature to less than 100°C (212°F). Underground layout and surface facility design are modified accordingly.

- **Continuous ventilation design**–Continuous ventilation is provided both during preclosure and after human presence in the repository is discontinued.

- **Enhanced access design**–This is a self-shielded waste package design that eliminates most underground remote handling operations.

- **Modified waste emplacement mode design**–Waste packages are emplaced in a configuration in which the repository's natural or engineered barriers provide shielding. This design concept includes vertical or horizontal emplacement in the floor or side wall of the emplacement drift and trench emplacement in the floor.

These five alternative design concepts do not represent a complete list of alternatives being evaluated for potential performance-enhancing benefits. These design concepts are, however, representative of the type of design work that is being or will be undertaken before a reference design is selected to support site recommendation and the LA. In addition, many of the design features that were not incorporated into the five alternative design concepts will be evaluated further in separate design studies.

8.3 DESCRIPTION OF THE ALTERNATIVE DESIGN CONCEPTS

This section briefly describes each of the five alternative design concepts developed for the VA. Figures are provided where needed to demonstrate the concept. These alternatives have not yet been evaluated, and the figures provided are notional. Therefore, it is neither intended nor possible to make a complete, detailed presentation of these alternatives in this document. The concepts illustrated in the accompanying figures will likely evolve as the analysis proceeds.

Each alternative is described in terms of the important attributes of the surface waste handling facility, overall subsurface layout, emplacement drift-scale arrangement, and waste package configuration. For comparison, these same important attributes of the VA reference design, particularly those that illustrate differences between the VA reference design and the alternative design concepts, are summarized below.

- **Surface facility**–The surface waste handling facility is described in Section 4.1. It consists of five parallel processing lines. Three of these lines will handle commercial spent nuclear fuel that does not arrive in disposable canisters, while the remaining two will handle waste that arrives in disposable canisters. The facility has a throughput capacity that will accommodate the number of waste packages associated with the large waste package concept described in Section 5.1. This throughput is expected to be in the range of 500 to 550 waste packages/year.

- **Subsurface layout**–The VA reference design is based on a high thermal load and requires a very low level of continuous ventilation after emplacement. Approximately 157 km (98 miles) of drifts are required, and the emplacement area totals approximately 741 acres; the subsurface layout for the VA reference design is shown in Figure 8-1. This layout can be developed in a single, contiguous emplacement block that is located between the Ghost Dance fault on the east and the Solitario Canyon fault on the west. Two vertical air shafts and two ramps provide access from the surface.

- **Emplacement drift-scale arrangement**–The waste packages are emplaced within a 5.5-meter (18-ft) diameter drift on metal supports. The emplacement drifts will not be backfilled at closure, and no postclosure ventilation is planned. No human access is planned, under normal conditions, after waste emplacement has begun in an emplacement drift.

- **Waste package configuration**–Large waste packages with two metallic barriers and a capacity of 21 pressurized-water reactor or 44 boiling-water reactor spent nuclear fuel assemblies are the nominal spent nuclear fuel containers. Smaller containers, with a capacity of 12 pressurized-water reactor or 24 boiling-water reactor assemblies, will be used for assemblies that exceed thermal or criticality potential parameters for the large containers. The waste package does not provide sufficient shielding to allow personnel access.

The important attributes of the surface waste handling facility, overall subsurface layout, emplacement drift-scale arrangement, and waste package configuration for each of the five alternative design concepts are described in the following sections.

8.3.1 Waste-Specific Containment Design Concept

Under this alternative, each waste type would be placed in a container specifically designed for its characteristics. The waste would be segregated in specific areas in the underground and the emplacement drifts would be designed to promote long-term survivability of the specific container type.

- **Surface facility**–The surface facility would be required to handle a wider assortment of container types. It is possible that different metals would be used for different waste forms, leading to a possible need for multiple production technologies.

- **Subsurface layout**–A layout similar to the VA reference design, shown in Figure 8-1, could be used for this alternative. If it is determined that the alternative would work better in a low thermal load configuration, the layout may look similar to the arrangement shown in Figure 8-2.

- **Emplacement drift-scale arrangement**–Within each drift, the arrangement would appear similar to the VA reference design. The primary difference would be that all containers in a given drift would be of the same type and contain the same waste form. The layout would segregate different wastes in areas specifically selected to best match performance characteristics suited to disposal of the specific waste type.

- **Waste package configuration**–Each waste form would have its own container configuration design.

The waste-specific containment design is based on the concept that each different type of waste (commercial spent nuclear fuel, DOE-owned spent nuclear fuel, surplus weapons-useable plutonium, and defense high-level radioactive waste glass) would be placed in a container especially designed for its characteristics. The system's performance may be enhanced by shedding water from warmer to cooler regions of the repository. However,

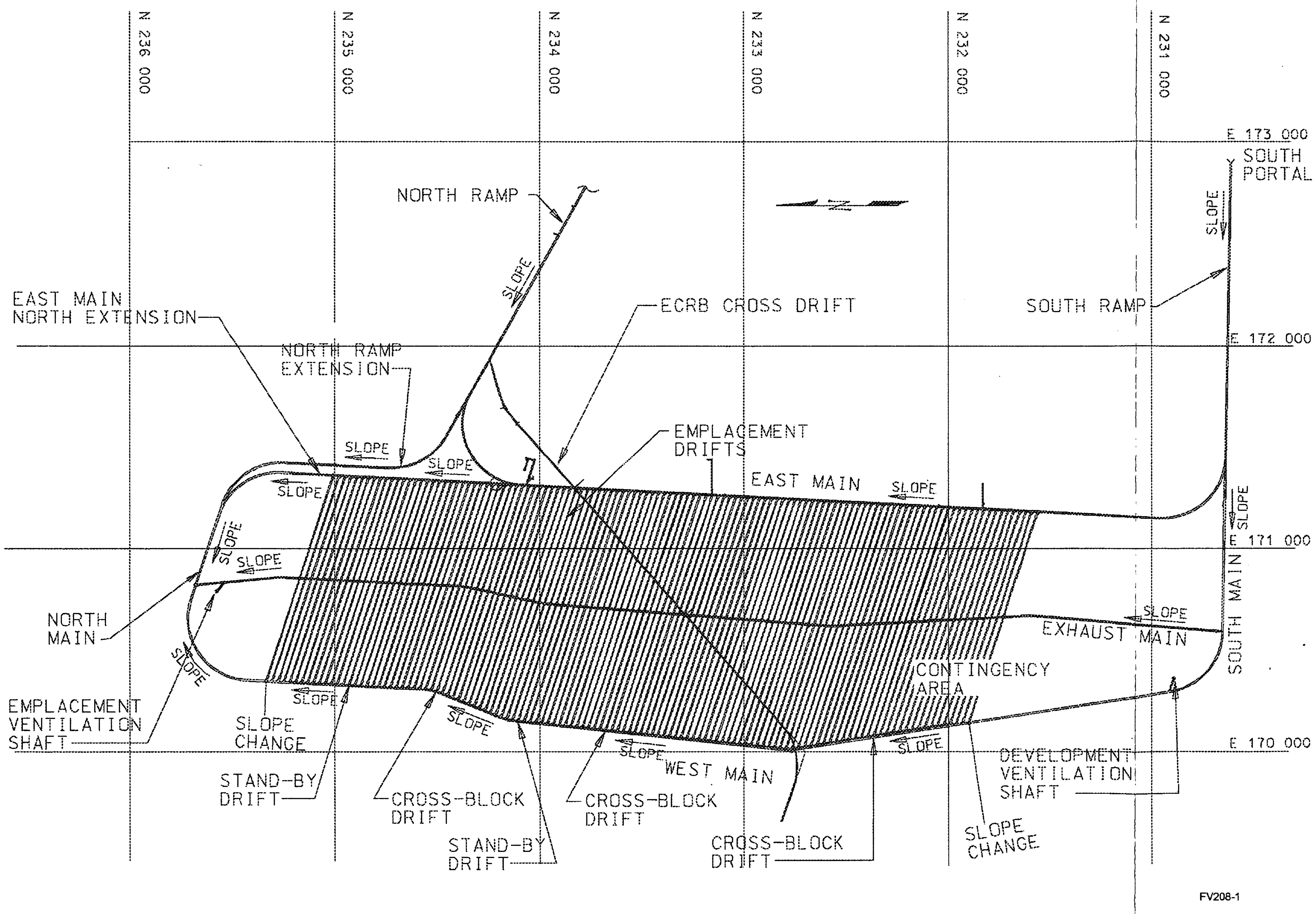

Figure 8-1. Subsurface Repository Layout Reference Design

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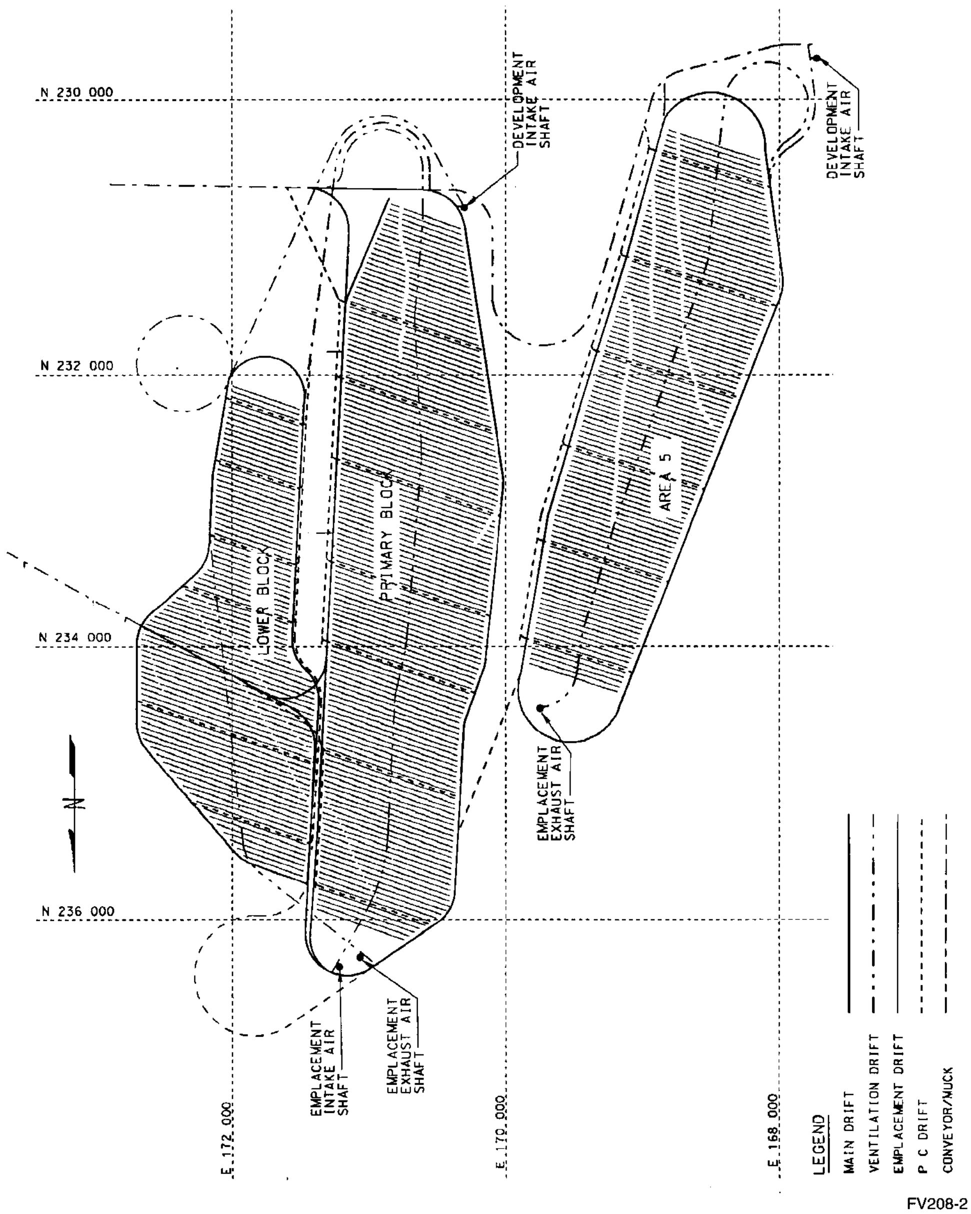

Figure 8-2. Twenty-Five Metric Tons of Uranium per Acre - 63,000 Metric Tons of Uranium Inventory

uneven thermal loading could also result in gradients across the repository that could affect performance. Developing a unique optimum design for each waste type could potentially improve performance. Licensing strategies could be content specific, which could enhance the strategies. Alternatively, the licensing strategies could be impacted by the added complexity required to deal with the different waste types. In either case, the effort to implement a waste-specific containment design could result in different sets of terms and conditions in the license. Waste-type-specific, unique packages could facilitate licensing discussions. Facility costs could increase because this design does not commingle wastes. It may also take longer and cost more to fabricate, load, and handle packages because of the number of processes involved. Specific wastes could be placed in the most desirable location of repository if it were possible to understand the character of the mountain sufficiently prior to starting emplacement. Alternatively, adapting to varying site conditions could be more difficult because each waste type would have to be considered separately. The potential additional handling could increase worker risk.

8.3.2 Low Thermal Load Repository Design Concept

This alternative limits the emplacement drift rock temperature to less than 100°C (212°F), requiring the underground layout and surface facility design to be modified accordingly.

- **Surface facility**–The change to a smaller capacity waste package would require a large increase in the number of containers to be processed. The surface waste handling building would, therefore, probably require a higher throughput capacity. The number of commercial spent nuclear fuel waste packages required for this design concept would be approximately 15,000. The actual number would depend on the waste package capacity that is ultimately selected for this alternative.

- **Subsurface layout**–The subsurface layout would encompass 2,500 acres of useable emplacement area. Figure 8-2 shows the conceptual layout for a 70,000 MTU, 25 MTU/acre design concept. Additional site characterization may be required if the layout cannot be contained in the primary area currently being characterized. The amount of area required possibly could be reduced by ventilating the emplacement drifts.

- **Emplacement drift-scale arrangement**–The VA reference design configuration using in-drift emplacement on a container support would be employed in this alternative. It may be possible to reduce the drift size from its current 5.5-meter (18-ft) diameter, but drift temperatures will increase as drift diameter decreases, if all other parameters are held constant. If the objective is to maintain lower temperatures, it may not be desirable to substantially reduce the drift size.

- **Waste package configuration**–To maximize the effect of a low thermal load, it is desirable to reduce the maximum waste package capacity from that used in the VA reference design. The exact container capacity has not yet been defined, but is likely to be less than 12 pressurized-water reactor or 24 boiling-water reactor elements. This will have the effect of more evenly distributing the heat and reducing or eliminating the number of small above-boiling zones. The container would not be shielded for human access.

A low thermal load repository is intended to limit the temperature rise of the host rock that results from the decay heat of the emplaced waste. This approach has the potential to cause less change in the emplacement environment than does the high thermal load. If very little or no rock is heated above the boiling point of water, the changes from ambient temperature should be less severe, and the resulting waste package environment uncertainty could be reduced. Coupled thermal, hydrological, mechanical, and chemical effects are probably less difficult to describe in lower temperature situations, possibly leading to enhanced licensing strategies. This advantage, however, could be offset because additional data might be needed for a larger site area.

There is also a potential for improved performance because corrosion rates and waste form degradation rates are less at lower temperatures. Also, having waste packages below the boiling point of water could reduce ponding above the drifts and result in less potential for thermal impact on zeolites below the drifts. However, lower temperatures could limit rock dryout, and hence, more water could be available to contact the waste.

There could be short-term schedule impacts due to the need to characterize additional area. In addition, there could be long term schedule impacts due to the additional construction and greater number of waste packages required. Short-term costs could be reduced because it may be simpler to characterize the geotechnical properties required to analyze performance required for a lower thermal load; however, long-term costs could increase due to the increased number of waste packages and additional construction required. Variability in site conditions may be less significant for lower thermal loads. Safety could be improved because of easier access at lower temperatures and less disturbance of the rock mass. The increased amount of tunneling required could, however, potentially increase worker risk.

8.3.3 Continuous Ventilation Design Concept

This alternative calls for continuous ventilation both during the preclosure period and after human presence in the repository is no longer required.

- **Surface facility**–The surface facility design for this alternative concept would be similar to that for the low thermal load alternative described in Section 8.3.2.

- **Subsurface layout**–The subsurface layout would be similar to that shown in Figure 8-2. However, this alternative would require several additional airshafts to pass the airflow needed to continuously ventilate the emplacement drifts at the rate required to keep them cool. The heat produced by the emplaced waste, coupled with the phenomenon known as natural ventilation pressure, could help supplement the preclosure ventilation and would provide the sole means of postclosure ventilation. Natural ventilation pressure is naturally induced air flow that is driven by a difference in air density between the air intakes and the exhaust ventilation openings. In the repository application, the waste decay heat provides a means of producing warm, low-density exhaust air. This condition will induce flow from the cooler intakes through the facility to the warmer exhaust openings.

Figure 8-3 shows a conceptual layout of one way in which continuous ventilation, supplemented by natural ventilation pressure, could be provided during the preclosure. An additional feature of this layout is the location of exhaust shafts along the exhaust main. This requires that spaces in the otherwise continuous array of emplacement drifts be left so that these air shafts can pass through the emplacement area to connect with the underlying exhaust main. While this strategy will consume a portion of otherwise usable emplacement area, it will allow the movement of large volumes of air flow into and out of the subsurface without the need for long runs of large-diameter main drifts. Additionally, this concept tends to divide the subsurface into "cells" or "modules" which would be advantageous in the event of a subsurface fire.

Figure 8-4 shows a variation of the subsurface layout with the exhaust main located above the emplacement area instead of below, as is the case in the VA reference design. This arrangement would promote postclosure natural ventilation pressure-driven circulation through the emplacement drifts. Air would flow from the east and west edges of the layout toward the center, up the vertical connections into the exhaust main drift, outward to the edges of the repository in the overlying performance confirmation drifts, and back down to the perimeter main drifts through vertical

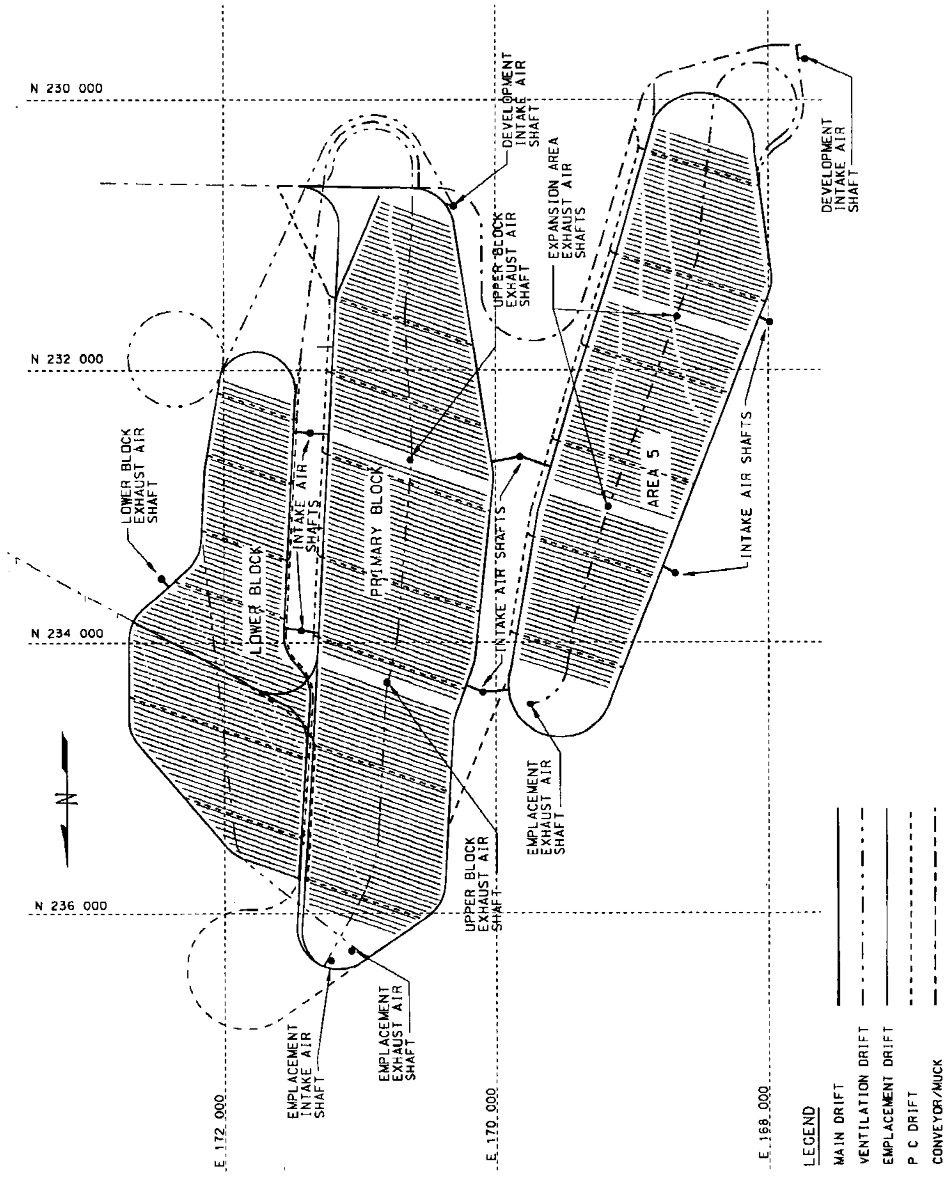

Figure 8-3. Twenty-Five Metric Tons of Uranium per Acre - 63,000 Metric Tons of Uranium Inventory with Additional Shafts

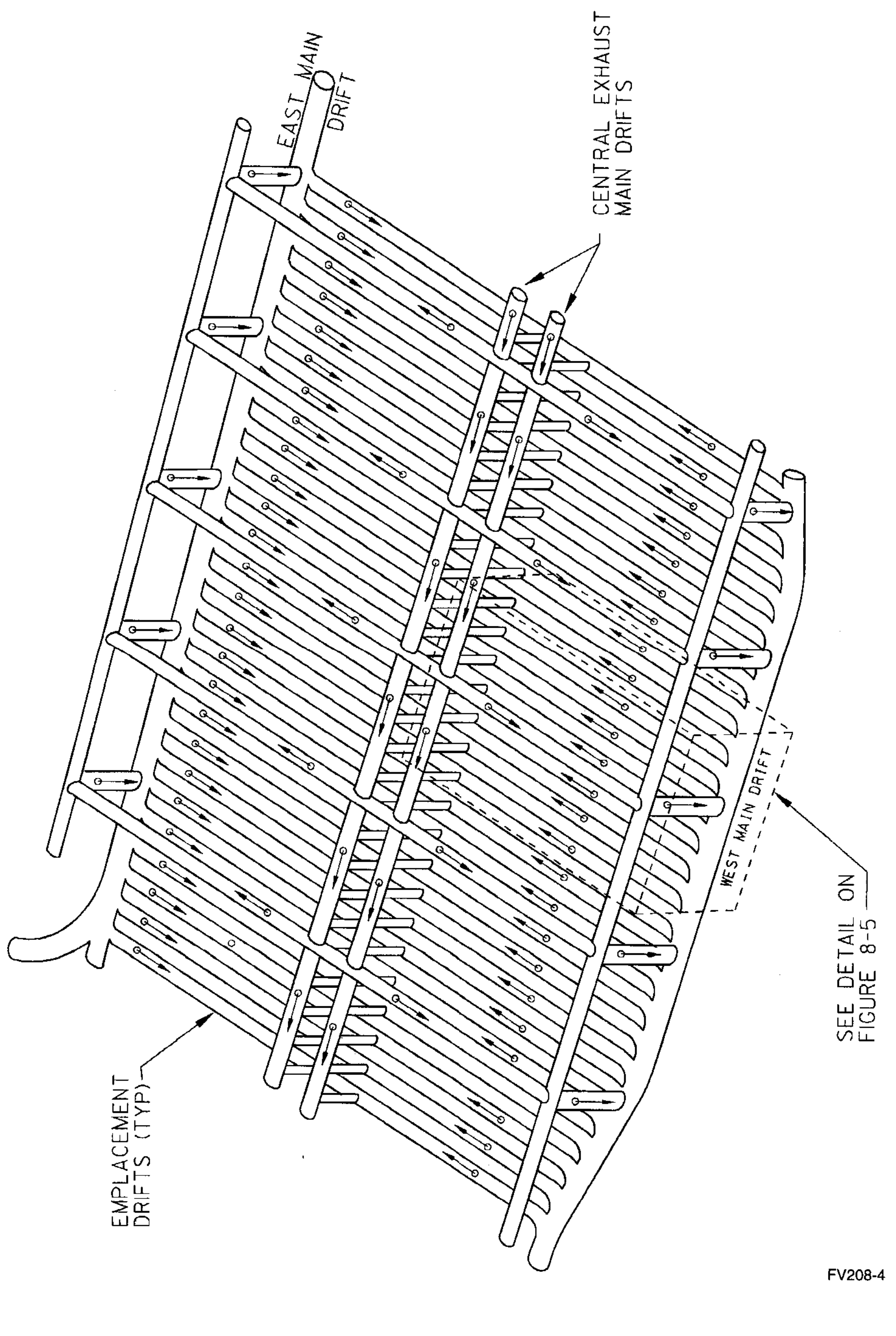

Figure 8-4. Exhaust Mains Above Emplacement Area

connections. This is the closed-loop recirculation system proposed by Danko (1997). His calculations indicate that the heat of the emplaced waste will drive a small flow of air for an extended time period after closure. Figure 8-5 shows a single flow cell from the overall configuration shown in Figure 8-4.

Another concept that may provide a cooler and less aggressive waste package corrosion environment is one in which the emplacement drift is ventilated continuously both during the preclosure period and after human presence at the repository is discontinued. Water must be present for significant waste package corrosion to occur, and continuous ventilation of the drifts could remove water from the emplacement environment and maintain low relative humidity around the waste packages.

- **Emplacement drift-scale arrangement**–For this alternative, the emplacement drift arrangement would be similar to that of the VA reference design.

- **Waste package configuration**–The waste package configuration for this alternative would be similar to that of the VA reference design.

This alternative has several of the attributes of the low thermal load alternate discussed in Section 8.3.2. It employs both a low thermal load and a smaller capacity waste package. The design may also be adaptable to high thermal loading. The major difference with this option is that ventilation is provided continuously from the time of waste emplacement through the end of manned operations, and beyond this time for as long as the subsurface openings remain intact and able to pass air flow.

Removing water from the system in combination with lower temperatures could enhance performance.

The complexity of the ventilation system, uncertainty in ventilation models, and qualifying ventilation models pose licensing challenges, as does the difficulty in demonstrating integrity of the ground support system after closure. The additional construction required could result in long-term cost and schedule impacts. It may be difficult to modify emplacement strategies in response to site conditions after the ventilation system has been constructed. Institutional controls might be needed to ensure safe operation, increased tunneling could increase worker risk, and siting additional shafts could be impacted by topographic constraints. The potential for gaseous dispersion of radionuclides could be increased after the waste packages breach. Any leaking packages would be detected as long as monitoring of the ventilation system continues.

8.3.4 Enhanced Access Design Concept

This alternative specifies a self-shielded waste package design that eliminates most underground remote handling operations.

- **Surface facility**–The surface facility for this design concept would be similar to those alternatives requiring a larger number of waste packages. Processes may also be required to handle and close the thicker-walled waste packages needed for shielding. In addition, the increased number of waste packages would require a high throughput capability.

- **Subsurface layout**–This alternative can employ a high thermal load, which allows the total 70,000 MTU inventory to be placed in a single emplacement block within the primary area. The ventilation arrangement is similar to that described in Section 8.3.3, in that several additional air shafts are needed and are placed around the perimeter of the block, as well as down the center of the facility. Figure 8-6 shows a possible configuration of the layout for this alternative.

- **Emplacement drift-scale arrangement**–The emplacement drift configuration would be similar to the VA reference design. The emplacement drift environment, however, would be different because the temperature would be maintained at or below approximately 50°C (122°F), and the radiation level

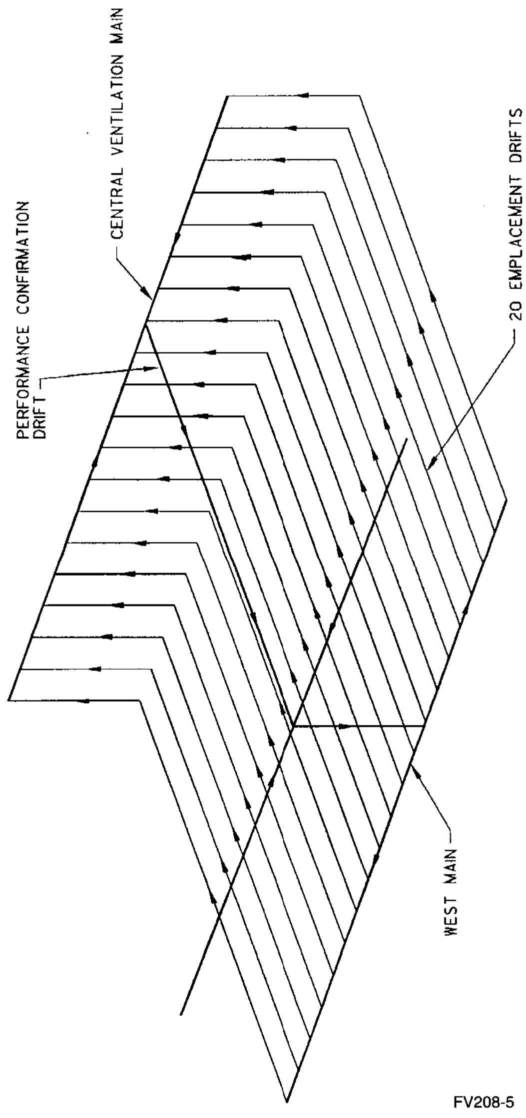

Figure 8-5. Closed-Circuit Natural Ventilation Pressure Cell

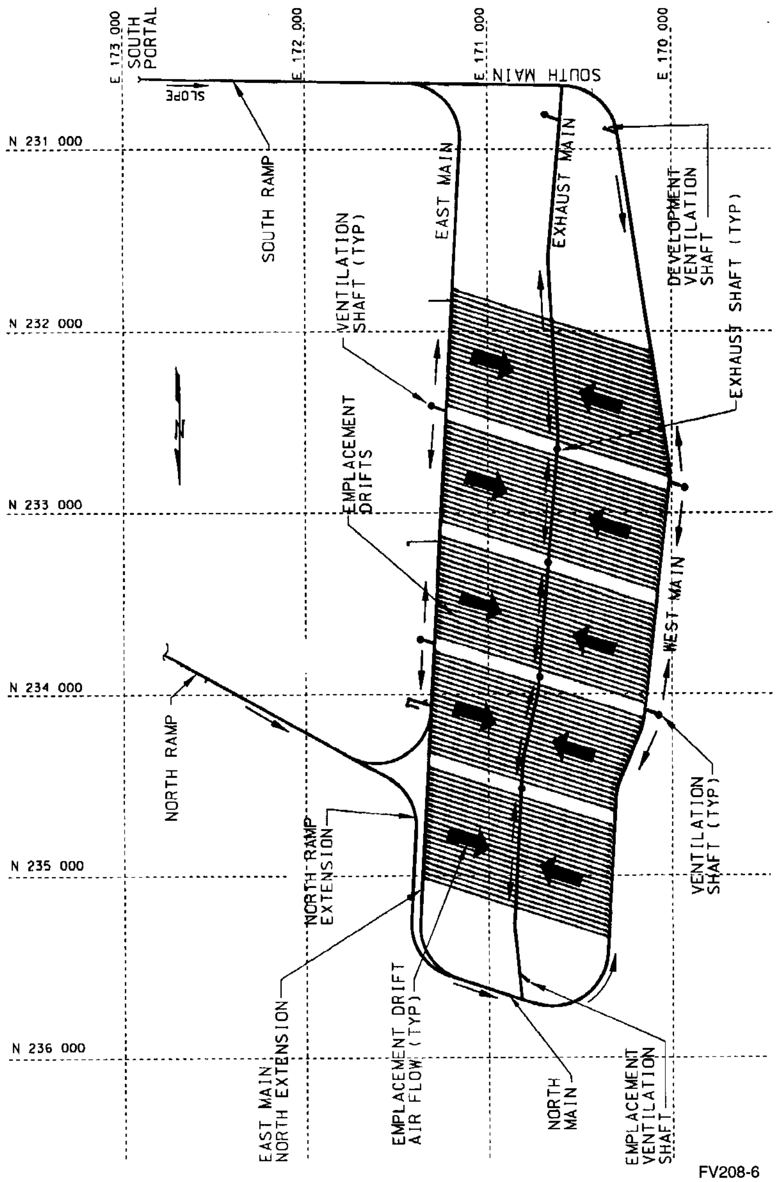

Figure 8-6. Continuous Ventilation Subsurface Repository Layout

would be low enough to permit occasional human access. A trade-off is necessary between the allowable frequency and duration of access and the amount of shielding required.

- **Waste package configuration**–The waste package in this alternative is a self-shielded container with a capacity of up to 12 pressurized-water reactor or 24 boiling-water reactor assemblies. It has a considerably thicker outer barrier than the container specified in the VA reference design. However, because it provides its own shielding, a shielded transporter is not required. The waste packages could be moved by locomotives on a rail-mounted vehicle and directly emplaced by a manned operation.

This alternative uses a waste package that provides sufficient shielding to allow human access to the emplacement environment. The VA reference design requires remote handling for emplacement and precludes human access to the emplacement drifts when waste packages are present. Coupled with the shielding aspect is the use of increased ventilation to control the temperature in the emplacement drifts.

Using more corrosion-allowance material may slightly improve performance. Also, the shielding could act as a drip shield. This alternative design could increase the ability to inspect the engineered barrier system because human entry would be allowed. It could also be easier to defend the inspection process during licensing hearings.

Development of the design would impact the short-term schedule, and there could be additional costs associated with the shielding material, additional waste packages, and potentially more complex operations. The shields themselves may be expensive. However, the ability to inspect individual packages facilitates identification of waste packages that could be moved to accommodate varying site conditions. Human entry allows intervention for remedial action. Safety could be impacted by ease of handling and by eliminating the need for remote access. The increased amount of handling could, however, increase worker risk and could offset the potential for decrease in radiation exposure.

8.3.5 Modified Waste Emplacement Mode Design Concept

Under this alternative, unshielded waste packages are emplaced in a configuration where the repository's natural or engineered barriers provide shielding. This design includes place waste packages in boreholes drilled into the floor or wall of the emplacement drift or within trenches excavated in the emplacement drift floor.

- **Surface facility**–As with other alternatives requiring small-capacity containers, this alternative would require a higher throughput from the surface waste handling facility and an increase in the total number of waste packages required.

- **Subsurface layout**–A low thermal loading is planned for this option. It would be difficult to attain a high thermal load with the small-container concept because both the containers and the drifts would have to be spaced close together. The layout for this option would be similar to that shown in Figure 8-3.

- **Emplacement drift-scale arrangement**–This alternative offers many possible variations for the emplacement mode. One option would be to place the containers in boreholes drilled either vertically into the drift invert (floor) or horizontally, slightly slanted to provide drainage, into the side wall of the drift. The borehole could be lined with metal or ceramic to enhance performance. A shield plug would be placed in the collar of the hole after the container is emplaced. Another option would be to construct a slot or trench in the floor of the emplacement drift, place the containers in the trench, and then place a slab over the open trench to provide shielding. Figures 8-7 and 8-8 show potential borehole options. Figure 8-9 shows the trench option.

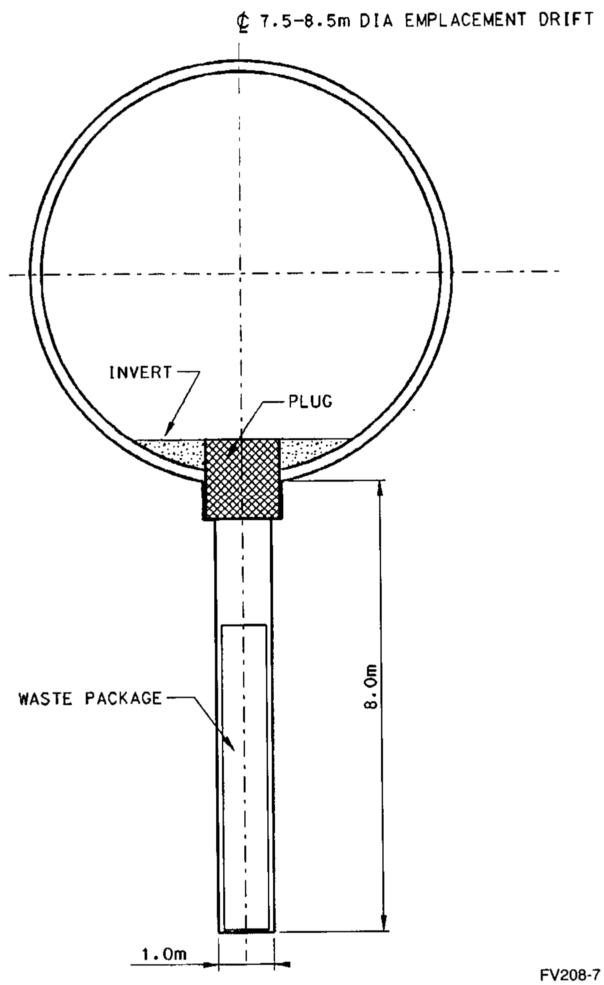

Figure 8-7. Vertical Emplacement

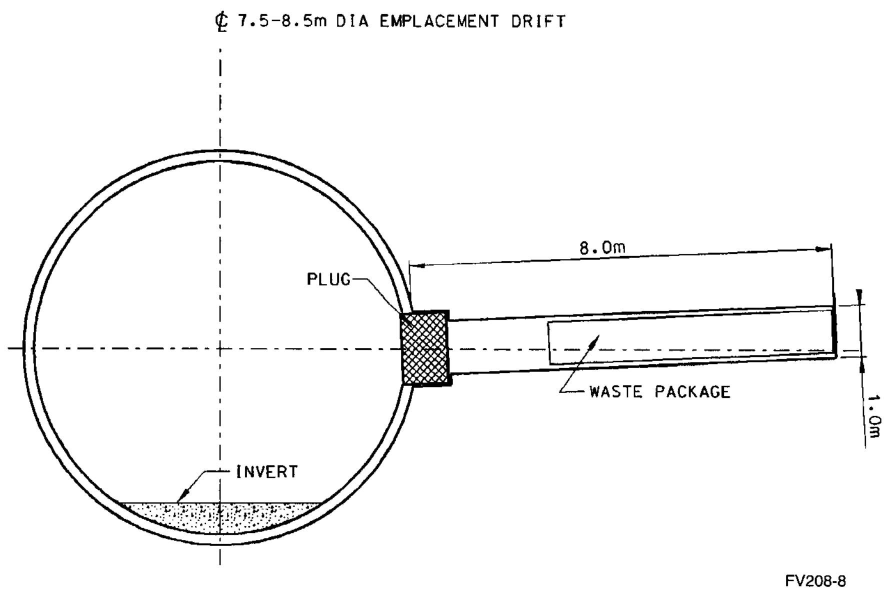

Figure 8-8. Horizontal Emplacement

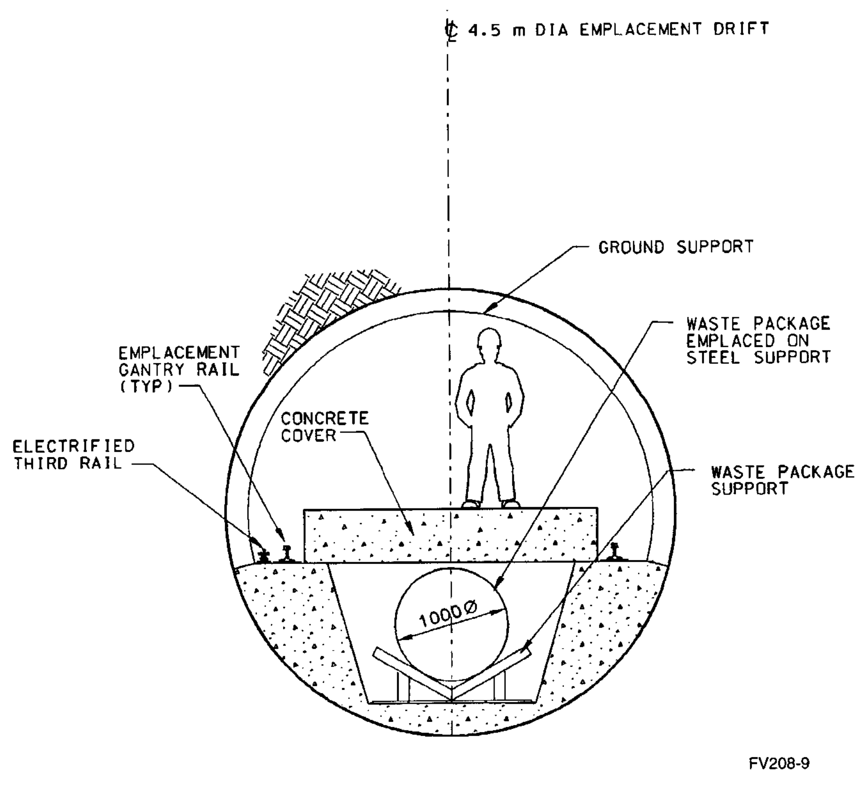

Figure 8-9. Small Package in Trench

The borehole options could require a larger diameter emplacement drift than required in the VA reference design. The larger diameter would be required because of the length of the waste packages, the size of the borehole drilling and waste package emplacement equipment, and the fact that the waste packages must be rotated from the centerline axis of the drift so that they can be placed in the boreholes. Alternatively, a small drift diameter could be used for horizontal emplacement by drilling the boreholes at an angle to the drift. The trench concept may allow a somewhat smaller drift diameter because of the smaller waste package (compared to the VA reference design) and because the waste package would not need to be rotated within the drift.

- **Waste package configuration**–The waste package designs for this alternative may incorporate the same multiple-barrier concept, but will have much smaller capacities. This is because the waste package will be placed in a very confined area. The waste package will not be able to radiate heat effectively, and the capacity must be low enough to ensure that the containers do not overheat.

The modified waste emplacement mode option would involve the use of unshielded waste packages having a smaller waste capacity than specified in the VA reference design. The waste packages would, however, be emplaced in a shielded configuration in the subsurface. This concept, in conjunction with continuous ventilation for cooling, would allow ready access to the emplacement drift after the completion of waste emplacement within the drift. Because the containers are unshielded, the subsurface transportation and emplacement would be remotely controlled.

Performance could be impacted by mechanical deformation of the boreholes, which could also limit capillary effects. Thick-walled containers would not be compatible with borehole emplacement; however, the waste packages could be maintained at temperatures below the boiling point of water. Fuel debris from breached waste packages could be concentrated in small area, especially in the vertical borehole configuration. The waste packages could, however, be prone to overheating.

Although the emplacement drifts would be accessible, the waste packages would not be as readily accessible. There are potential cost and schedule impacts associated with the increased number of waste packages. Increased difficulty in observing emplacement borehole conditions impacts the ability to respond to changed site conditions. The waste packages would be shielded resulting in easier worker access, although emplacement could be more problematic. Increased handling could increase worker risk.

8.4 INFORMATION NEEDED TO ADDRESS DESIGN FEATURES AND ALTERNATIVE DESIGN CONCEPTS

As noted previously, the design features and alternative design concepts described in this section are developed to the level to identify design studies needed to support the selection of the initial site recommendation and the subsequent LA design. For each of the design features and alternative design concepts described in this section, information that is relevant to evaluation of the performance enhancement potential of that design feature or alternative design concept has been identified. The related information for the design features is presented in Table 8-5. The related information for the alternative design concepts is presented in Table 8-6. The related information provides a link to the work plans in Volume 4 that are important to evaluations of the design features and the alternative design concepts, and therefore, to eventual selection of the initial site recommendation and the LA design.

8.5 SUMMARY AND CONCLUSIONS REGARDING ALTERNATIVES DESIGN

The information presented in this section should provide a basis for understanding DOE's approach to evaluating potential benefits of certain design features or alternative design concepts, as well as

Table 8-5. Related Information Important to Evaluations of Potential for Performance Enhancement for the Identified Design Features

DESIGN FEATURE	RELATED INFORMATION
Aging (Pre-Emplacement) of Waste	Parameters related to desired thermal loading/time profile
Blending of Waste (for Thermal or Criticality Considerations)	Parameters related to desired thermal loading/time profile, storage pool costs versus MTU of stored waste
Waste Handling Building Production Lines	Critical interfaces impacted by multiple production lines, cost per line and throughput per line
Continuous Ventilation	Parameters related to ability of ventilation system to remove heat and moisture from system
Rod Consolidation	Parameters related to desired thermal loading/time profile, industry experience related to implementation.
Timing of Repository Closure	Ventilation impacts on parameters related to desired thermal loading/time profile, performance confirmation plans
Underground Features and Ground Support (Maintained and Not Maintained)	Parameters related to impact on retrievability, and backfilling, expected life of systems without maintenance
Drift Diameter	Drift size, ground support, drift stability, time, cost relationships
Waste Package Shielding	Radiation levels for different materials, impact of organics on performance
Waste Package Corrosion-Resistant Materials (Metal and Ceramic)	Aqueous corrosion temperatures, chemistry interactions
	Behavior mechanisms for combinations: CRM over CAM, Dual CRM, CRM over CAM over CRM
	Longevity and performance of ceramic materials
Barriers	Parameters related to performance of Richards barrier, effectiveness and longevity of capillary barriers
	Parameters related to performance of diffusive barrier, permeability, longevity
	Parameters related to performance of getter material under the WP, effectiveness and longevity of chemical materials
Internals	Parameters related to potential performance enhancements of canistered assemblies, corrosion resistance, interactions.
	Parameters related to potential performance enhancements of additives and fillers
Ground Support	Parameters related to performance of metal-lined drift, drift size, ground support, drift stability, time relationships, maintenance and frequency plan
	Parameters related to performance of drift, drift size, ground support, drift stability, time relationships, maintenance and frequency plan, with and without concrete
Near-Field Rock Treatment During Construction	Parameters related to treatment, enhanced drift stability, time relationships, grouting parameters and impacts on hydrologic performance over time
Surface Modification	Parameters related to modification of alluvial cover, longevity and effectiveness, erosion, evapotranspiration in the long term, sources of inflow, fill material characteristics and infiltration parameters
	Parameters related to modification of surface drainage, longevity and effectiveness, erosion

the plans developing the design that will support site recommendation and the LA. In particular, it is important to recognize DOE has put in place plans to evaluate both design features and, where appropriate, to support implementation of design-specific features and alternative design concepts. The five alternative design concepts presented in this section are intended to present examples of the types of alternative layouts to the VA reference design that could be considered. It appears that potential to enhance the performance of nearly any alternative design can be found in the features identified in Table 8-2. The design studies that will support selection of the LA reference design will consider the performance enhancements that can be developed from these design features. Information regarding performance, licensing, cost, schedule, and safety has been provided to indicate the types of system and design studies that need to be performed to support the selection of the reference

Table 8-6. Related Information Important to Evaluations of Potential for Performance Enhancement for the Five Viability Assessment Alternative Design Concepts

DESIGN CONCEPT	RELATED INFORMATION
Waste Specific Containment Design	Parameters related to shedding of water from warmer to cooler regions of the repository
	Parameters related to uneven thermal loading induced gradients across repository and resultant hydrologic and mechanical importance, thermal map (contours) of emplacement area for different time periods during and after emplacement
	Parameters related to unique optimum design for each waste type: waste form characteristics (solubility & colloids), container material degradation characteristics
	Content specific licensing strategies and analyses to deal with different waste types related to retrievability, different water and rock chemistry distribution in the mountain
	Parameters needed to fully understand the character of the mountain prior to starting emplacement so that wastes could be placed in the most desirable location for waste type, distribution of waste based upon moisture distribution, fracture zones, rock chemistry, distribution of introduced materials
Low Thermal Load Design	Waste package corrosion rates and waste form degradation rates as a functions of temperature
	Potential for ponding above drifts, limited rock dryout, and water available to contact the waste, rock permeability in different formations and potential perched water locations
	Understanding of coupled thermal/hydrological/mechanical/chemical effects in lower temperature environment; potential simplification in coupled models
	Characterization of greater geographic area related to infiltration parameters, rock unit parameters, structural parameters
	Thermal thresholds for no impact on important rock properties
	Solubility relationships for radionuclides as a function of temperature, with and without concrete
	Solubility, desorption, filtration, and stability information for colloids as a function of temperature, with and without concrete
	Requirements for additional construction and waste package production lines related to designs, size, number, and materials
Continuous Ventilation Design	Parameters related to removal of water from system by ventilation, rock mass saturation as function of temperature and time, exchange coefficients, ventilation air relative humidity, air velocity, air temperature, location of high-efficiency particulate air filters
	Dispersion coefficients following breach of waste packages, both in gaseous forms and solid forms, source terms for releases into ventilation system
	Reduction in uncertainty in models of ventilation, and qualifying ventilation models
	Cost and development parameters for active ventilation schemes, ventilation costs
	Parameters related to the physics of passive ventilation schemes, coupled to rock temperatures which are affected by waste heat, total ventilation flows as a function of atmospheric winds, pressure, and temperature
Enhanced Access Design	Selection of shielding material, production technologies, radiation levels, and attenuation versus material thickness for different materials
	Parameters related to performance of shielding as corrosion allowance material, general pit and crevice corrosion
	Inspection technologies, (including performance confirmation) in radiation environment, estimated system life and estimated maintenance schedule
	Viability of shielding as a drip shield
	Drift size, ground support, drift stability, time relationships, costs versus drift size for excavation and different ground support
	Enhanced access through shielded access vehicle, reliability, costs, survivability with breakdown in emplacement drift
Modified Waste Emplacement Mode Design	Waste package size, thermal load density, hole size, temperature relationships
	Performance confirmation parameters for specific designs
	Parameters related to mechanical deformation, seepage and capillary effects, sensitivities to type of emplacement
	Criticality potential related to fuel debris from breached canisters concentrated in small area, conditions and poisons to prevent, if needed
	Drilling and emplacement technologies, costs for different hole sizes, drilling times for different hole sizes

design that will support the site recommendation and be included in the LA.

The design features and alternative design concepts presented in this section are intended to span a broad range of potential concepts that vary substantially from the VA reference design. Evaluation of design features and alternative design concepts is intended to ensure both that DOE carries forward a good overall Monitored Geologic Repository concept, and that it facilitates compliance with regulatory requirements regarding consideration of alternative design concepts for major design features that are important to waste containment and isolation.

Work on developing these alternative designs, including system and trade studies, is underway and will continue into 1999. By mid year, DOE expects to make the selection of the initial repository safety strategy case to support the LA. That decision will guide the selection of an initial reference design to support preparation of the site recommendation and the LA. That design could be an evolved version of the VA reference design, one of the alternatives described in this section, or a different alternative selected following completion of system, design or trade studies.

The process of selecting the initial design that will support site recommendation and the LA will be documented, both to support NRC requirements to consider alternative designs of major design features important to waste isolation and containment, and to facilitate understanding of the process by oversight agencies. It may prove prudent to carry with the site recommendation and the LA reference design additional features, similar in concept to the options to the VA reference design, which could enhance the performance of the design.

9. SUMMARY

Volume 2 presents reference designs for the repository surface and subsurface facilities, and for the waste package. The VA reflects the VA reference design and is current as of March 1998. The VA reference design is used in performing the total systems performance assessments discussed in Volume 3.

The design will continue to progress between now and the time any license application is submitted to NRC just as the design has evolved to the present one since the development of the earlier Site Characterization Plan conceptual design. In developing its designs, DOE has solicited and received feedback from NRC staff, NRC's Advisory Committee on Nuclear Waste, the independent Nuclear Waste Technical Review Board, the Repository Design Consulting Board, several expert elicitation panels and peer review groups, and the international community. DOE will continue to evaluate feedback on its design activities from these professional groups.

DOE has employed an integrated systems engineering approach in developing its designs. Such an approach is particularly important in developing designs for the subsurface facility and the waste package. Models have been developed, based on site information and proposed designs, and performance assessments have been conducted and evaluated. Based on the results of these assessments, the designs have been modified, as appropriate, to enhance the predicted performance of the design items under evaluation. Design options have been identified which may enhance the performance of the engineered barrier system. Also, major alternatives to the reference design are under consideration. Evaluations of options and major alternatives are ongoing and will be completed prior to submittal of any license application.

In developing its preclosure safety case, DOE will continue to rely to the maximum extent practicable upon equipment, processes, and operations already approved by NRC and in use at other licensed nuclear facilities. The spectrum of equipment, processes, and procedures already approved by NRC at such facilities includes spent nuclear fuel receipt, transfer, and other handling operations designed to ensure protection of the workers as well as the health and safety of the public.

In developing its postclosure safety case, DOE will continue to rely on the complementary roles that the natural and engineered barrier systems are expected to play in achieving the safety objectives of a repository system located above the water table in the unsaturated zone at Yucca Mountain. These objectives include containing the radionuclides within the waste packages for thousands of years and ensuring that the annual doses to persons living near the site will be within the bounds of natural variations in background radiation.

Four key attributes have been identified through insights gained from a series of interim total system performance assessments and from information obtained from materials testing, site investigations, and design studies. These attributes are those that appear to contribute significantly to containing waste and limiting doses to nearby members of the public and which appear to be quantitatively demonstrable.

The four key attributes of an unsaturated repository system that are critical to meeting the objectives are as follows:

- Limited water contacting the waste packages
- Long waste package lifetime
- Slow rate of release of radionuclides from breached waste packages
- Radionuclide concentration reduction during transport through the engineered and natural barriers

DOE will continue to focus the remaining technical work related to repository performance on these key attributes and the confirmation of their associated hypotheses.

The VA is a major project milestone and is one of several milestones that must be reached over the next four years for DOE to accomplish its mission.

Work is in progress to achieve these ensuing milestones, which includes preparation and distribution of the EIS; preparation and issuance of the site recommendation report; and, if appropriate, submittal of an LA. Submittal of the LA is scheduled for March of 2002.

Significant progress has been made at the Yucca Mountain site over the past several years. Development of the Exploratory Studies Facility has opened up the host rock for detailed examination and ongoing construction of a cross-block drift that will yield additional data on the lower rock units that make up the repository horizon. The drilling program continues to provide data on stratigraphy, rock characteristics, and the hydrologic system near the repository block. Continuing evaluation of this data will help to continue the progressive evolution of the repository design as the YMP moves toward scheduled submittal of the LA.

The work that remains to be completed between the VA and the submittal of any license application and the resources required to perform such work are discussed in detail in Volume 4 of the VA. Volume 5 addresses the overall costs, beginning with docketing of the LA with NRC, and includes costs associated with complete repository and engineered barrier system designs, construction and operation, and closure and decommissioning of the repository.

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The numbers at the end of each reference are Office of Civilian Radioactive Waste Management document accession numbers. See the inside front cover of this document for whom to contact regarding more information.

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APPENDIX A

GLOSSARY

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GLOSSARY

Many of the definitions in the glossary are Project Specific.

Accessible Environment	(1) The atmosphere, the land surfaces, surface water, and oceans beyond the controlled area that humans or animals may contact. (2) The area surrounding a nuclear waste disposal site.
Adsorb	To collect a gas, liquid, or dissolved substance on a surface as a condensed layer.
Advanced Conceptual Design	The design phase that was used to explore selected design alternatives and firmly fix and refine the design criteria and concepts to be made final in later design efforts. The project feasibility was demonstrated, life-cycle costs estimated, preliminary drawings prepared, and a construction schedule developed as required by DOE Order 6410.1.
Air Lock	A chamber or room in which air pressure can be regulated, usually located between two regions of unequal pressure. The isolation air locks each consist of two bulkheads with doors that are opened and closed in sequence.
Altered Zone	The rock adjacent to the emplacement drifts that is most strongly affected by the presence of the emplaced waste.
Ambient	Surrounding. Used in the total system performance assessment to mean undisturbed, natural conditions such as ambient temperature caused by climate or natural subsurface thermal gradients.
Architecture	The physical system to be built, found, or selected to perform a function subject to its stated requirements.
Areal Mass Loading	The amount of heavy metal (usually expressed in metric tons of uranium or equivalent) emplaced per unit area in the proposed repository.
Assembly Transfer	Refers to the movement of individual spent fuel assemblies from a transportation cask to a waste disposal container.
Backfill	(1) The general fill that is placed in the excavated areas of the underground facility. Backfill for the repository may consist of tuff excavated from the underground facility. (2) The material or process used to refill an excavation.
Balance of Plant	Nonradiological-related surface facilities.
Barrier	Any material, structure, or condition (as a thermal barrier) that prevents or substantially delays the movement of water or radionuclides.
Baseline	Documentation of current or ambient conditions to serve as a basis for identifying and/or measuring changes.

Basket	Refers to an inner component of the waste package that provides support for individual spent fuel assemblies. For example, the basket for the disposal containers for spent nuclear fuel resembles an egg crate put together with interlocking plates. Also refers to a portable metal framework used to accomplish assembly transfer in the Waste Handling Building.
Binning	A project-specific term that refers to the process of prioritizing systems, structures, and components based on their importance to radiological safety as well as regulatory or design precedent.
Biosphere	The ecosystem of the earth and the living organisms inhabiting it.
Blast Cooling	The act of rapidly cooling by supplying a large quantity in air over a short period of time. The emplacement drifts will be blast cooled before retrieving any emplaced waste packages.
Block	The portion of Yucca Mountain, which is partially blocked off by faults, that has been designated as the Monitored Geologic Repository site. Also referred to as the main block and the waste emplacement block.
Bogie	The electric motors that drive the gantry crane wheels so the crane can travel along the underground rail system.
Boiling-Water Reactor	A nuclear power reactor that produces steam in the primary system.
Bolster	A support plate used to strengthen a larger plate at a specific area.
Borated	Containing boron, a neutron absorber used in criticality control.
Borehole	A hole drilled for purposes of collecting information about an area's geology or hydrology. Sometimes referred to as a drillhole or well bore.
Bridge Crane	A large overhead crane used for material handling that spans across rails or either side of a building.
Brinell Hardness Number	The Brinell hardness number is a measure of relative hardness. The test involves forcing a steel ball into a test piece under standard conditions and then measuring the surface area of the resulting indentation.
Bulkhead	A wall or embankment in a mine or tunnel that protects against earth slide, fire, water, or gas.
Burnup	A measure of nuclear-reactor fuel consumption expressed either as the percentage of fuel atoms that have undergone fission or as the amount of energy produced per unit weight of fuel.
Burnup Credit	Credit taken, when spent fuel has been in a reactor, to account for that part of its fissionable content that has been consumed. Used for calculating criticality.
Btu	British thermal unit. The amount of heat required to increase the temperature of one pound of water one degree Fahrenheit.

Canister	The containment vessel surrounding the waste (e.g., high-level radioactive waste immobilized in glass rods) that facilitates handling, storage, transportation, and/or disposal. A metal receptacle with the following purposes: (1) a pour mold for solidified high-level radioactive waste and (2) for spent fuel, structural support for loose rods, non-fuel components, or containment of radionuclides during postclosure operations. See Disposable Canister and Non-Disposable Canister.
Canister Transfer Cell	Refers to the removal of disposable waste canisters from a transportation cask and placing them in a waste disposal container. This operation is done remotely in a concrete-shielded room.
Carrier	A large truck- or rail-mounted transportation used to haul high-level radioactive waste across United States highways or railroads.
Carrier Bay	A receiving area at the Waste Handling Building for transportation carriers and casks.
Carrier Preparation	The operations associated with removal of personnel barriers and impact limiters for transportation casks.
Cask	A large, shielded container for shipping or storing spent nuclear fuel and/or high-level radioactive waste that meets all applicable regulatory requirements.
Cask Drop	Refers to a hypothetical accident event that assumes a transportation cask is dropped during waste handling.
Cementitious Material	A material made of or having the characteristics of cement, a substance that hardens to function as an adhesive.
Cladding	The metallic outer sheath of a fuel element generally made of a zirconium alloy or stainless steel. It is intended to isolate the fuel element from the external environment.
Closure	The final backfilling of the remaining open operational areas of the underground facility after the termination of waste emplacement, culminating in the sealing of shafts and ramps.
Collar	A structure that keeps the top of a shaft or borehole from falling in.
Colloid	As applied to radionuclide migration, a colloidal system is a group of large molecules or small particles that have at least one dimension with the size range of 10^{-9} to 10^{-6}m that are suspended in a solvent. Naturally occurring colloids in groundwater arise from clay minerals such as smectites and illites. Colloids that are transported in groundwater can be filtered out of the water in small pore spaces or very narrow fractures because of the large size of the colloids.
Commercial Fuel	Spent nuclear fuel from commercial nuclear power (see Spent Nuclear Fuel).

Commercial Grade	An item that is (1) not subject to design or specification criteria unique to the project or nuclear facilities, (2) used in applications other than the nuclear industry, and (3) ordered from the manufacturer or supplier on the basis of specifications set forth in the manufacturer's published product description, but which is used (and typically dedicated to) quality-affecting applications.
Compaction	The process of compressing a material, such as soil, so that it is firmly packed together.
Concrete	A construction material consisting of gravel, pebbles, broken stone, or slag in a mortar or cement matrix.
Containment	The retention, by physical barriers, of radioactive waste within a designated boundary for thousands of years.
Contamination	The intrusion of undesirable elements (unwanted physical, chemical, biological or radiological substances, or matter that has an adverse effect) to air, water, or land.
Control Rod	Movable pieces or assemblies of neutron-absorbing material such as cadmium, boron, and hafnium, position or insertion of which in a spent fuel assembly or configuration affects the nuclear reactivity of the assembly or configuration. In a disposal system, control rods are not expected to move, and their presence would reduce the reactivity of the configuration in which they are placed.
Corrosion-Allowance Material	Disposal container material, such as carbon steel, that oxidizes at a predictable rate in corrosive environments.
Corrosion-Resistant Material	Disposal container material, such as Alloy 22, that oxidizes slowly in a corrosive environment.
Crane	A machine for hoisting and moving heavy objects by cables attached to a movable arm.
Creep Rupture	Failure of a material caused by deformation under constant load.
Criticality	The condition in which nuclear fuel sustains a chain reaction. It occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle. For the TSPA-VA, it is a condition that would require the original waste form, which is part of the waste package, to be exposed to degradation followed by conditions that would allow concentration of sufficient nuclear fuel, the presence of neutron moderators, the absence of neutron absorbers, and favorable geometry.
CRWMS (Civilian Radioactive Waste Management System)	The composite of the sites and all facilities, systems, equipment, materials, information, activities, and personnel required to perform those activities necessary to manage radioactive waste disposal.

dBA	An abbreviation for the A-weighted sound level in decibels. The A-scale is a measurement of sound approximating the sensitivity of the human ear and is used to note the intensity or annoyance of sound.
Decontamination	A process that removes, destroys, or neutralizes chemical, biological, or radiological contamination from a person, object, or area.
Defense High-Level Nuclear Waste	The high-level radioactive waste generated in the course of weapons production and reprocessing of spent nuclear fuel in a defense facility. (See High-Level Radioactive Waste.)
Defense in Depth	The addition of features to enhance a design; providing extra layers of backup protection or insurance beyond the original design features for unanticipated events or parameters.
Degradation	Deterioration of the waste package barrier, primarily by corrosion and oxidation.
Design Bases	Information that identifies the specific functions to be performed by items and the specific values or ranges of values chosen for controlling parameters as reference bounds for design.
Design-Basis Events	Naturally or humanly induced events that may occur before permanent closure of the geologic repository's operations area.
Detection	The act of discovering or discerning the existence or presence of an object or substance.
Diesel	An internal-combustion engine that uses the heat of highly compressed air to ignite a spray of fuel introduced after the start of the compression stroke.
Diffusive Barrier	Backfill or other material placed beneath the waste packages to retard the transport of radionuclides released from breached waste packages.
Disposable Canister	A containment vessel structure licensed for dry storage, transportation, and subsequent disposal in the repository. This type of canister can be placed directly into a disposal container and eliminates the need to open the canister and repackage individual fuel assemblies once it has been loaded for storage. It is expected that defense high-level radioactive waste forms and most DOE-owned spent nuclear fuel will be received in disposable canisters. Formally referred to as a multi-purpose canister. See Canister.
Disposal	The emplacement in a monitored geologic repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste and the isolation of such waste from the accessible environment.

Disposal Container	The vessel consisting of the barrier materials and internal components in which the canistered or uncanistered waste form is placed. The filled, sealed, and tested disposal container is referred to as the waste package, which is emplaced underground.
Dose	The amount of radioactive energy that passes the exchange boundaries of an organism (e.g., skin and mucous membranes) and is taken into living tissues. Dose arises from a combination of the energy imparted by the radiation and the absorption efficiency of the affected organism or tissues. It is expressed in terms of units of the radiation taken in, the body weight or mass impacted, and the time over which the dose occurs or the impact is measured.
Drift	From mining terminology, a horizontal underground passage. The nearly horizontal underground passageways from the shaft(s) to the alcoves and rooms. Includes excavations for emplacement (emplacement drifts) and access (access mains).
Drill-and-Blast	The controlled drill-and-blast practices used may include presplit or cushion blasting or use of multiple delays with light explosives on each delay. These methods are intended to minimize blasting-induced damage to the rock surrounding the repository openings.
Dry Bulb (Temperature)	Air temperature measured by a thermometer whose bulb (mercury holder at the bottom of a thermometer) is dry (exposed to air).
Dry Handling Operation	A sequence of waste handling steps that are performed without the presence of water for shielding or to confine containment.
Dry Transfer Cell	A large room or building space surrounded with concrete and steel radiation shielding to protect personnel from direct radiation exposure and radioactive material contamination. The cells are normally used for dry waste handling activities and operations that are conducted with remotely operated equipment.
Dual-Purpose Canister	A containment vessel structure designed to store and transport commercial spent nuclear fuel. Also see Non-Disposable Canister.
Earthquake	A series of elastic waves in the crust of the earth caused by abrupt movement easing strains built up along geologic faults or by volcanic action and resulting in movement of the earth's surface.
Effective Neutron Multiplication Factor (k_{eff})	A measurement of nuclear reactivity or criticality potential. Equal to the number of fissions in one generation divided by the number of fissions in the preceding generation, in a finite medium.
Egress	The act of going out; emergence. An opening or means of going out: exit.
Emplacement	The placement and positioning of canisters of spent nuclear fuel or high-level radioactive waste in prepared positions within a repository.

Engineered Barrier System	The waste packages and the underground facility. These are the human-designed, or engineered, components of the disposal system and the waste package.
Enrichment	The percentage of the fuel matrix that is fissile.
Environment	(1) Includes water, air, and land and all plants and humans and other animals living therein, and the interrelationship, which exists among these. (2) The sum of all external conditions affecting the life, development, and survival of an organism.
Exploratory Studies Facility	An underground laboratory at Yucca Mountain that includes a 7.9-km (4.9-mile) main loop (tunnel), a 2.8-km (1.75-mile) cross drift, and a research alcove system constructed for performing underground studies during site characterization. The data collected will contribute toward determining the suitability of the Yucca Mountain site as a repository, and some or all of the facility may eventually be incorporated into the proposed repository.
Fail-Safe	A design characteristic by which a unit or system will become safe and remain safe if a system or component fails or loses its activation energy.
Failed Fuel	Spent nuclear fuel with breaches in the cladding.
Fault (geologic)	A fracture in rock along which movement of one side relative to the other has occurred.
Finite-Element Model	A computer numerical analysis that divides a region of interest into discrete elements and represents the behavior of the elements with a set of simultaneous equations. Solution of the set of equations yields the behavior at discrete points within the region of interest.
Fissile	Capable of undergoing fission.
Fission	The splitting of a nucleus into at least two other nuclei resulting in the release of two or three neutrons and a relatively large amount of energy.
Fission Product	A complex mixture of radionuclides produced by the process of fission that includes radioactive and nonradioactive radionuclides as well as the daughter products of the radioactive decay of these nuclides. This can result in more than 200 isotopes.
Fissionable Material	Heavy radioactive atómic nuclei that can be divided into smaller parts, which are referred to as fission products.
Fractures	Breaks in rocks caused by the stresses that cause folding and faulting. A fracture along which there has been displacement of the sides relative to one another is called a fault. A fracture along which no appreciable movement has occurred is called a joint. Fractures may act as fast paths for groundwater movement.

Fuel Assembly	A number of fuel rods held together by plates and separated by spacers, used in a reactor. This assembly is sometimes called a fuel bundle. See Individual Spent Fuel Assembly.
Fuel Assembly Transfer Cell	A concrete shielded room where spent nuclear fuel assemblies are transferred remotely from driers into a waste disposal container.
Gamma Radiation	Electromagnetic radiation emitted during the radioactive decay process. The gamma ray is the most penetrating wave of radiant nuclear energy. It does not contain particles and can be stopped by dense materials such as concrete or lead.
Gantry	A movable crane carried on a four-legged portal frame that runs along rails.
Gaseous Convection	Transfer of heat resulting from the flow of gas past or over an object.
Geologic Repository	A system for disposing of radioactive waste in excavated geologic media, including surface and subsurface areas of operation, and the adjacent part of the geologic setting that provides isolation of the radioactive waste within the controlled area.
Grade or Gradient	The change in value of a quantity per unit distance in a specified direction. Slope: measurements are expressed in percent, feet per mile, or degrees.
Groundwater	Water contained in pores or fractures in either the unsaturated or saturated zones below ground level.
Groundwater Table	See Water Table.
Grout	A pumpable slurry of cement and water or cement and water mixed with fine sand.
Grouting	The process of injecting grout into the crevices of a rock.
Hazardous Waste	A solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infection characteristics may (a) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness, or (b) poses a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.
Heavy Metal	All uranium, plutonium and thorium used in a nuclear reactor.
High-Efficiency Particulate Air Filter	A filter with an efficiency of at least 99.95 percent that separates particles from an air exhaust stream before it is released to the atmosphere.

High-Level Radioactive Waste	(1) The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing, and any solid material derived from such liquid waste that contains fission products in sufficient concentrations. (2) Other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.
Host Horizon	See Repository Host Horizon.
Host Rock	The rock unit in which the repository will be located. For the repository at Yucca Mountain, the host rock would be the middle portion of the of the Topopah Spring Tuff Formation of the Paintbrush Group. See also Tuff.
Human Intrusion	The inadvertent disturbance of a disposal system by the activities of man that could result in release of radioactive waste. 40 CFR 191, Subpart B, requires that performance assessments consider the possibility of human intrusion.
Important to Radiological Safety	When referring to systems, structures, and components, those engineered features of the repository whose function is (1) to provide reasonable assurance that high-level radioactive waste can be received, handled, stored, and emplaced without exceeding the requirements of 10 CFR 60.111(a) for Category 1 design basis events, or (2) to prevent or mitigate Category 2 design basis events that could result in doses equal to or greater than the values specified in 10 CFR 60.136 to any individual located on or beyond any point of the boundary of the preclosure controlled area.
Important to Waste Isolation	See definition in CRWMS M&O QAP-2-1 (CRWMS M&O 1995b).
Individual Spent Nuclear Fuel Assembly	An array of nuclear fuel rods that have been irradiated and discharged from a nuclear power reactor.
Inert	Lacking active thermal, chemical or biological properties. An inert atmosphere is incapable of supporting combustion.
In Situ	In its natural position or place. The phrase distinguishes in-place experiments, conducted in the field or underground facility, from those conducted in the laboratory.

Invert	(1) The low point of something such as a tunnel, drift or drainage channel. (2) An engineered structure or material placed on excavated drift floors (the low points) to serve as structural support for drift transportation or emplacement systems. (For precast concrete, the proper name is invert segments, but they are commonly referred to simply as inverts.) Typical invert (segments) convert rounded excavated floors to flat level surfaces for transportation system use. Emplacement drift inverts may be specially designed to enhance the waste isolation and criticality prevention capabilities of the proposed repository through choice of invert materials or invert shape. Inverts may also be used to help channel water to improve repository drainage.
Irradiated	A condition resulting from the planned exposure of materials and components to the nuclear fission process. The state of being radioactive.
Isotope	One of two or more atomic nuclei with the same number of protons (i.e., the same atomic number) but with a different number of neutrons (i.e., a different atomic weight.) For example, uranium-235 and uranium-238 are both isotopes of uranium.
Joint	A fracture in rock, usually more or less vertical to bedding, along which no appreciable movement has occurred.
Key Technical Issue	Issues important for assessing the long-term safety of a potential Yucca Mountain repository, as defined by the NRC. The issues are (1) Support Revision of the EPA Standard/NRC Rule Making, (NRC 1997d); (2) Total System Performance Assessment and Integration, (NRC 1998b); (3) Igneous Activity, (NRC 1998c); (4) Unsaturated and Saturated Flow Under Isothermal Conditions, (NRC 1997e); (5) Thermal Effects on Flow, (NRC 1997f) (6) Container Life and Source Term, (NRC 1998a); (7) Structural Deformation and Seismicity (NRC 1997a); (8) Evolution of Near-Field Environment (NRC 1997b); (9) Radionuclide Transport (Sagar 1997); (10) Repository Design and Thermal-Mechanical Effects (NRC 1997c).
Legal-Weight Truck	A truck transportation carrier used to ship high-level radioactive waste across public highways that meets all applicable local, regional, and state laws for unrestricted use.
License Application	An application to the U.S. Nuclear Regulatory Commission for a license to construct a repository.
Low-Level Radioactive Waste	Radioactive waste that is not classified as high-level radioactive waste, transuranic waste, or byproduct tailings containing uranium or thorium from processed ore. Usually generated by hospitals, research laboratories, and certain industries.
Mechanical Excavation	Refers to excavating work performed using mechanical equipment such as a tunnel boring machine, roadheader, mobile miner, etc., as opposed to using drill-and-blast methods.

Metric Tons of Heavy Metal (MTHM)	A metric ton is a unit of mass equal to 1,000 kg (2,205 lb). Heavy metals include thorium, uranium, plutonium, and neptunium. When used in the Civilian Radioactive Waste Management Program, the term usually pertains to heavy metals in spent fuel. In this document, MTHM is equal to MTU (Metric Tons Uranium).
Metric ton of Uranium (MTU)	A metric ton, which is 1,000 kg or 2,205 lbs of uranium.
Missile	As used in Section 2 of this volume, refers to a tornado-driven projectile.
Mixed Waste	Waste containing both radioactive hazardous substances and nonradioactive hazardous substances, regardless of whether these types of substances are physically separated, combined chemically, or mixed together.
Monitor Phase	The period between emplacement of the last waste package and closure of the repository, which includes the activities of site security, performance confirmation and maintenance of subsurface and surface facilities to maintain the capability for waste package retrieval.
Monitored Geologic Repository	Any system licensed by the U.S. Nuclear Regulatory Commission that is intended to be used for, or may be used for, the permanent deep geologic disposal of high-level radioactive waste and spent nuclear fuel, whether or not such system is designed to permit the recovery, for a limited period during initial operation, of any materials placed in such system. This term includes both surface and subsurface areas at which high-level radioactive waste and spent nuclear fuel handling activities will be conducted. The repository will be monitored between emplacement of the last waste package and closure.
Muck	Material excavated from a mine or geologic repository.
Multipurpose Canister	See Disposable Canister.
National Environmental Policy Act	The federal statute that is the national charter for protection of the environment. The Act is implemented by procedures issued by the Council on Environmental Quality and DOE. The *National Environmental Policy Act of 1969* appears at 42 U.S.C. 4321 et seq.
Natural Barrier	The physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that individually and collectively act to limit or preclude radionuclide transport.
Natural System	A host rock suitable for repository construction and waste emplacement and the surrounding rock formations. It includes natural barriers that provide containment and isolation by limiting radionuclide transport through the geohydrologic environment to the biosphere and provide conditions that will minimize the potential for human interference in the future.

Naval Spent Nuclear Fuel	Spent nuclear fuel discharged from reactors in surface ships, submarines, and training reactors operated by the U.S. Navy.
Near-Field	The region where the adjacent natural geohydrologic system has been significantly impacted by the excavation of the repository and the emplacement of the waste.
Near-Field Environment	The condition of the area near the repository. This condition may change because of heat, water influx, and chemical changes in the rock itself.
Neutron Radiation	The emission of neutrons from radioactive materials.
Nondisposable Canister	A containment vessel that is licensed for dry storage and transportation, but not for disposal at the Monitored Geologic Repository. This type of canister cannot be placed directly into a disposal container, but must be opened and the individual fuel assemblies repackaged before being placed in the disposal container for emplacement. See Canister and Dual-Purpose Canister.
Nuclear Safety Analysis	For this document, refers to the process used to evaluate the hazards and safety risks associated with nuclear energy systems operations.
Nuclear Waste	Spent nuclear fuel and residue from nuclear weapons production that is stabilized in a solid form.
Nuclear Waste Policy Act (42 USC 10101 et seq.)	The federal statute enacted in 1982 that established the Office of Civilian Radioactive Waste Management and defined its mission to develop a Federal system for the management and geologic disposal of commercial spent nuclear fuel and other high-level radioactive wastes, as appropriate. The Act also specified other federal responsibilities for nuclear waste management, established the Nuclear Waste Fund to cover the cost of geologic disposal, authorized interim storage under certain circumstances, and defined interactions between Federal agencies and the states, local governments, and Indian tribes. The act was substantially amended in 1987 and 1992.
Nuclide	An atomic nucleus specified by its atomic weight, atomic number, and energy state; a radionuclide is a radioactive nuclide.
Off-Normal Conditions	Unplanned events or conditions that adversely affect, potentially affect, or indicate degradation of, the safety, security, environmental or health protection, performance, or operation of a facility. Examples include power failures, waste transportation and emplacement system malfunctions, and the presence of excessive water within an emplacement drift.
Offset	Geologic term for displacement of formerly contiguous bodies; in a fault, the horizontal component of displacement.
Operating Galleries	A shielded room or corridor adjacent to assembly transfer areas or areas where operators can safely and remotely control or observe radioactive materials and equipment.

Operation (Operational) Phase	The period between receipt of the first waste package and emplacement of the last waste package in the repository that includes ongoing construction of subsurface facilities, operation and maintenance of subsurface and surface facilities, performance confirmation activities, procurement of waste packages, and operation of the transportation system.
Overpack	A secondary container used to hold or contain one or more smaller canisters.
Pascal (Pa), Kilopascal (kPa)	The standard international unit of pressure; defined as one newton per square meter. A newton is the force necessary to give an acceleration of 1 m/s^2 to 1 kg of mass. One Pa equals 0.000145 $lb/in.^2$; 1 kPa equals 0.145 $lb/in.^2$.
Performance Confirmation	The program of tests, experiments, and analyses conducted to evaluate the accuracy and adequacy of the information used to determine, with reasonable assurance, that the performance objectives for the period after permanent closure will be met.
Permeable	Pervious. A permeable rock refers to a rock, either porous or cracked, that allows water to soak into and pass through it freely.
Permeability	In general terms, the capacity of a medium like rock, sediment, or soil to transmit liquid or gas. Permeability depends on the substance transmitted (oil, air, water, etc.) and on the size and shape of the pores, joints, and fractures in the medium and the manner in which they are interconnected. "Hydraulic conductivity" has replaced "permeability" in technical discussions relating to groundwater.
Pneumatic Actuator	A mechanical device or component operated by compressed air or gas that is used to control.
Pool	Refers to a steel-lined concrete structure designed to hold water for handling or storing spent nuclear fuel and casks.
Portal	Surface entrance to a mine, particularly in a drift, tunnel, or adit. The North Portal and South Portal are the two primary accesses to the subsurface facilities.
Postclosure Controlled Area	A surface location, to be marked by suitable monuments, extending horizontally no more than 10 km in any direction from the outer boundary of the underground facility and the underlying subsurface which has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure (10 CFR 60).
Postclosure Period	The period of time after the closure of the geologic repository.
Potable Water	Drinking water.

Preclosure Controlled Area	That surface area surrounding the geologic repository operations area for which the licensee exercises authority over its use, in accordance with the provisions of 10 CFR 60, until permanent closure has been completed (10 CFR 60).
Preclosure Period	The period of time before and during the closure of the geologic repository.
Pressurized-Water Reactor	A nuclear power reactor that produces steam in a secondary system.
Primary Area	The surface location of the principal area that is suitable or is under consideration for waste emplacement. When projected downward along the location of faults and other geologic features, the boundaries of the primary area encompass the principal region within the target emplacement horizon that is considered potentially suitable for waste emplacement.
Prime Mover	Project-specific term referring to a heavy-tire or rail-mounted vehicle used to transport high-level radioactive waste carriers.
Probable Maximum Flood	The hypothetical flood (peak discharge, volume, and hydrograph shape) that is considered to be the most severe reasonably possible, based on comprehensive hydrometeorological application of probable maximum precipitation and other hydrological factors, such as sequential storms and snowmelts, that are favorable for maximum flood runoff.
Programmable Logic Controller	A small computer module that can be programmed to execute specific instructions to control equipment or motion.
Qualitative	With regard to a variable, a parameter, or data, an aspect that is expressed or described with nonnumeric qualities or attributes.
Quantitative	A variable that is expressed numerically.
Radiation Absorbed Dose	The unit of absorbed dose from radiation exposure.
Radioactive Decay	The process in which one radionuclide spontaneously transforms into one or more different radionuclides, which are called daughter nuclides.
Radioactive Waste	High-level radioactive waste and other radioactive materials, including spent nuclear fuel, that are received for emplacement in a geologic repository.
Radiolysis	The chemical dissociation of molecules due to radiation.
Radionuclide	Radioactive type of atom with an unstable nucleus that spontaneously decays, usually emitting ionizing radiation in the process. Radioactive elements characterized by their atomic mass and number.
rem (Roentgen equivalent man)	The unit of a dose equivalent from ionizing radiation to the human body. It is used to measure the amount of radiation to which a person has been exposed.

Remediation	Action taken to permanently remedy a release or threatened release of a hazardous substance into the environment, instead of or in addition to removal. To prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health or welfare or the environment.
Repository	Repository refers to any system licensed by NRC that is intended to be used for, or may be used for, the permanent deep geologic disposal of high-level radioactive waste and spent nuclear fuel.
Repository Construction	All excavation and mining activities associated with the construction of ramps and necessary openings in the underground facility, preparatory to radioactive-waste emplacement, as well as the construction of necessary surface facilities, but excluding site-characterization activities.
Repository Design Consulting Board	An oversight committee created by the Management and Operating Contractor to review design, engineering, and management activities of the Management and Operating contractors.
Repository Host Horizon	10 CFR 960 specifies that the host rock be of sufficient thickness and lateral extent to allow significant flexibility in selecting the depth, configuration, and location of the underground facility. The layered sequence of rock strata meeting this criterion is collectively referred to as the repository host horizon.
Repository Layout	The host rock, depth and areal extent of the repository facility, drift size and spacing, mechanical support system, thermal loading, and ventilation system used during the operational phase of the facility. This is as mentioned in the *Energy and Water Development Appropriations Act, 1997.*
Repository Siting Volume	The three-dimensional mass of rock that is considered to be suitable for emplacement of the nuclear waste.
Restricted Area	An area, access to which is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. Does not include areas used as residential quarters, but separate rooms in a residential building may be set aside as a restricted area (10 CFR 60).
Retrieval	The act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal.
Roadheader	An underground excavating machine that uses either a transverse or in-line cutter head; used for specialty excavations, such as small chambers, when specially shaped openings that cannot be dug by the tunnel-boring machine are required.
Rockbolt	A bar, usually constructed of steel, that is anchored into predrilled holes in rock as a support or reinforcement device. The method of ground support utilizing such devices to support wall and ceilings in underground excavations.

Rockfall	The relatively free falling of a newly detached segment of rock of any size from a cliff, steep slope, cave, arch, or the roof (crown) of a tunnel.
Rock Mass Rating	A method of classifying a rock mass for purposes of selecting structural support for tunnels and for predicting certain rock mass properties, such as strength.
Sanitary Waste	Wastewater generated by non-industrial processes (e.g., showers, toilets, and food preparation).
Saturated Zone	The region below the water table where rock pores and fractures are completely saturated with groundwater.
Seal	An engineered barrier to prevent radioactive migration or the intrusion of undesirable substances. Specifically, in waste package closure, sealing of the lids by welding the closure lids into place.
Seismic	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
Seismic Event	An earthquake or a somewhat similar transient earth motion caused by an explosion.
Self-Sustained Neutron Chain Reaction	See Criticality.
Shaft	An excavation or vertical passage of limited area, compared to its depth, used for lowering men and material or ventilating underground workings.
Shielding	Any material that provides radiation protection.
Site Characterization	Activities, whether in the laboratory or in the field, undertaken to establish the geologic conditions and the ranges of the parameters of a candidate site relevant to the location of a repository. These activities include borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but do not include preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken.
Slab	A layer of concrete that commonly serves as the floor of any part of a building whenever the floor is in direct contact with the underlying soil.
Slurry	(1) A pumpable mixture of solids and liquids. (2) A mixture of liquid and finely divided insoluble solid materials. (3) A watery mixture of insoluble matter that results from some pollution control techniques.
Source Term	Types and amounts of radionuclides that are the source of a potential release from the repository.
Spall	To break off in layers parallel to a surface.

Spent Nuclear Fuel	Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing. Spent fuel that has been burned (irradiated) in a reactor to the extent that it no longer makes an efficient contribution to a nuclear chain reaction. This fuel is more radioactive than it was before irradiation, and it is hot. See also Burnup.
Spent Nuclear Fuel Rod	An individual tube or rod of a spent nuclear fuel assembly containing radioactive fuel pellets sealed inside.
Standoff	A neutralizing or counterbalancing effect.
Steel Lagging	Structural components, typically channel or plate members, that extend from steel set to steel set and provide additional support to the ground.
Steel Sets	Steel tunnel supports used in main entries of mines and shafts. The sections are I-beams for caps and H-beams for posts or wall plates, the H-section giving equal stiffness in two directions at right angles to each other.
Stress	The action on a body of a system of balanced forces whereby strain or deformation results. Stress is expressed as force per unit area, found by dividing the total force by the area to which the force is applied.
Stringer	A longitudinal construction member in a tunnel or bridge.
Tertiary	The first of two geologic periods of the Cenozoic Era extending from the end of the Mesozoic Era to the beginning of the Quarternary Period, from about 63 million to about two million years ago.
Thermal Loading	The application of heat to a system, usually measured in terms of watt density. The thermal loading for a repository is the watts per acre produced by the radioactive waste in the active disposal area. The spatial density at which waste packages are emplaced within the repository as characterized by the areal power density and the areal mass loading.
Thermocouple	A thermoelectric device used to measure temperature.
Thermal-Mechanical	Physical movement or deformation of rock caused by changes in temperature.
Total System Performance Assessment	A risk assessment that quantitatively estimates how the proposed Yucca Mountain repository system will perform in the future under the influence of specific features, events, and processes, incorporating uncertainty in the models and data. The purposes are to (1) provide the basis for predicting system behavior and testing that behavior against safety measures in the form of regulatory standards, (2) provide the results of TSPA analyses and sensitivity studies, (3) provide guidance to site characterization and repository design activities, (4) help prioritize testing and selection of the most effective design options.

Trunnions	Lifting attachments designed to facilitate handling of heavy casks, canisters, and containers.
Tuff	Igneous rock formed from compacted volcanic fragments from pyroclastic (explosively ejected) flows with particles generally smaller than 4 mm in diameter. The most abundant type of rock at the Yucca Mountain site.
Type I Faults	NRC defines Type I faults as faults that are subject to lateral or vertical movement and are of sufficient length and proximity to the repository that they may affect repository design and/or performance.
Uninterruptible Power Supply	A power supply that provides automatic, instantaneous power, without delay or transients, upon failure of normal power. It can consist of batteries or full-time operating generators. It can be designated as standby or emergency power, depending on the application.
Unsaturated Zone	The zone of soil or rock below the ground surface and above the water table in which the pore spaces contain water, air, and other gases. Also called the vadose zone.
Vitrified	Pertaining to a type of processed high-level radioactive waste where the waste is mixed in a liquid form with glass-forming chemicals and put through a drying and melting process. The melted mixture is then put into a canister where it becomes a dry "log" of waste in a glassy matrix.
Vitrophyre	An igneous rock containing large crystals in a pronounced glassy groundmass.
Washdown	The process of washing, spraying, rinsing, and cleaning a vehicle, carrier, or cask to remove dirt and debris.
Waste Form	A generic term that refers to radioactive materials and any encapsulating or stabilizing matrix. There are five general categories of waste forms that will be emplaced in the proposed repository: (1) spent fuel from commercial nuclear reactors, (2) high-level radioactive waste, (3) spent nuclear fuel from DOE programs, including spent fuel from the U.S. Naval Nuclear Propulsion program, and (4) immobilized plutonium.
Waste Handling	Refers to transporting, lifting, unpackaging, packaging, and transferring waste forms at the Monitored Geologic Repository.
Waste Package	A loaded, sealed, and tested disposal container.
Wastewater	Spent or used water from individual homes, a community, a farm, or an industry that contains dissolved or suspended mater. Includes domestic sewage and industrial effluent. Wastewater discharging from sanitary conveniences such as toilets, showers, and sinks.
Water Table	The upper surface of a zone of saturation above which the majority of pore spaces and fractures are less than 100 percent saturated with water most of the time (unsaturated zone), and below which the opposite is true (saturated zone).

Welded Tuff	A tuff that was deposited under conditions where the particles making up the rock were heated sufficiently to cohere. In contrast to nonwelded tuff, welded tuff is considered to be denser, less porous, and more likely to be fractured (which increases permeability).
Wet Bulb (Temperature)	(1) Temperature measured by a thermometer whose bulb (mercury holder at the bottom of a thermometer) is covered with a cotton wick that is saturated with water (wet). (2) The lowest temperature that a water-wetted body will attain when exposed to an air current.
Wet Handling Operation	A sequence of waste handling steps that are performed under water to provide radiation shielding and confine contamination.

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Viability Assessment of a Repository at Yucca Mountain